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Faculty of Social Sciences
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MASTER'S THESIS

Effect of foreign exchange interventions on volatility of dollar/yen exchange rate

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Declaration of Authorship

The author hereby declares that she compiled this thesis independently; using only the listed resources and literature, and the thesis has not been used to obtain a different or the same degree.

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Signature

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Abstract

Japanese monetary authorities used to employ various intervention techniques to adjust the level of the dollar/yen exchange rate and reduce its volatility. Application of the GARCH-in-mean model for estimation of the effect of these operations demonstrates that depreciating interventions reduced volatility effectively from 1995 until 2002. Frequent interventions of the small scale had a tendency to increase volatility during period 1991-1995. Foreign exchange interventions conducted by US Fed have increasing, means negative, effect, on the conditional variance. Frequent interventions of the great scale do not affect the volatility; it is determined mostly by the persistent level of the conditional variance from the latter periods. Recent interventions conducted by the Bank of Japan after the financial crisis do not show any considerable effect on both the volatility and the level of the exchange rate.

JEL Classification	F31, F33, C32, C58
Keywords	foreign exchange rate, volatility, intervention, regime, GARCH model

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Acronyms

BoJ Bank of Japan

MoF Ministry of Finance of Japan

US United States

US Fed The Federal Reserve System

Master's Thesis Proposal

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Proposed Topic:

Effects of foreign exchange interventions on volatility of dollar/yen exchange rate

Motivation:

After United States dollar and the euro, Japanese yen is the third largest currency traded in the foreign exchange market (FX market). It is also often described by traders as a "safe heavens" currency.

Currency pair USD/JPY, in particular, is traded in the highest volume compared to other pairs coupled with yen. Cyclical appreciation in tandem with global economic recessions is, therefore, expected of yen. To that effect, suspicion of seasonality in the time series is a grounded assumption. But most importantly, exchange rate policies, over the last three decades, have impacted the yen volatility more than any other factor.

Similar to the United States, Japanese government preserve the right to oversee exchange rate matters. A segregated monetary oversight in Japan is carried out by both the Bank of Japan (BoJ) and Ministry of Finance (MoF). Each is respectively in charge of domestic and foreign monetary policies. Under auspices of International Finance Bureau (IFB), a bureau of MoF, issues such as exchange rate stability and currency internationalisation are dealt with independent of the Central banking authority to a major extend. In doing so, IFB intervenes in the FX market at times officially and most of the time secretively. Ito (as cited in Tagaki 2015) considers 1995 and 2004 the "dividing points" in intervention tactic paradigm shift. Before the appointment of Eisuke Sakakibara in 1995, he states, the Bureau intervened in the FX market frequently and in small sums. The pattern took an opposite from post-1995, where interventions were carried out barely one time every two months yet in notably higher amounts. Whereas after 2004, when Mizoguchi took over the office, the tactic turned hawkish meaning the interventions became both more frequent and larger in size.

Dukich, Kim, and Lin (2010) evaluate the performance of GARCH models for modelling daily changes in logarithmic exchange rates. They consider three exchange rate series - GBP/USD, JPY/USD, EUR/USD. For each sequence, the authors fit three GARCH models, with varying numbers of parameters, and attempt to replicate the empirical sequence via simulation. GARCH (1,1), GARCH (1,2), GARCH (2,1) models are used, and then the adequacy of each model is assessed. Tests of model adequacy are performed by simulating each GARCH model and comparing it to the corresponding empirical sequence. None of the GARCH models considered in the analysis captures the empirical nature of the exchange rate series particularly well; each model failed to adequately reproduce the sudden shift in variability associated with the financial crisis. Moreover, histograms of the

residuals show mixed results. Residuals for the JPY/USD sequence appear to be slightly heavier-tailed or skewed left. Thus, while each sequence satisfies the assumptions underlying the GARCH model, the GARCH model does not appear to faithfully reflect the empirical nature of those sequences.

There are also some papers which discuss the effects of Japanese foreign exchange intervention. Sterilised foreign exchange interventions were a subject of discussion on their capability to achieve a desired level of the exchange rate or reduce volatility. According to Rogoff (1984) in the portfolio balance models foreign and domestic assets are imperfect substitutes and, as a result, sterilised intervention can influence the exchange rate by changing the relative supplies and thereby the relative returns of foreign and domestic assets. According to Sarno and Taylor (2001), most of the papers from the past provide one with more evidence for the successful interventions; there are also conflicting results of the empirical studies on the effects of the foreign exchange rate intervention on the volatility as well as the level of the exchange rate.

In Japan, foreign exchange intervention was a widely used tool of the monetary policy until recent times. And, as a result, there are various points of view on the scale of the effect that these operations have on the volatility and level of the exchange rate. Estimations vary from no influence at all to relationships of the opposite signs, although the same data are used (Ito 2003, Fatum and Hutchison 2003, Castren 2004, Watanabe and Harada 2006).

Hillebrand and Schnabl (2006) studied the effects of Japanese foreign exchange interventions on the volatility of the yen/dollar exchange rate between April 1991 and October 2004 using daily intervention data released by the Japanese Ministry of Finance. There is contradictoriness detected in the GARCH estimations of the effect of Japanese foreign exchange intervention on the volatility of the yen/dollar exchange rate on the global level. At the same time, local estimations demonstrate that a structural break occurred around the turn of the millennium. As a result of a liquidity trap, Japanese foreign exchange intervention could effectively remain unsterilized. Authors come to the conclusion that up to the late 1990s, increased volatility of the yen/dollar exchange rate is a consequence of Japanese foreign exchange intervention. Exchange rate volatility had been decreasing after the application of foreign exchange intervention after the year 1997, so the level of the yen/dollar exchange rate had a tendency to stabilise.

Hypotheses:

1. Hypothesis 1 – Effects of the BoJ's interventions are not symmetric regarding the decreasing/increasing volatility of the USD/JPY exchange rate during the studying period from 1991 to 2011.
2. Hypothesis 2 – The Japanese foreign exchange interventions do not have a long-lived impact horizon.
3. Hypothesis 3 – Large lot interventions of low frequency in the short run do not have higher stabilising power factor than the large lot interventions of high frequency.

Methodology:

As the topic is mostly related to the time series, it would be appropriate to use GARCH model to test hypothesis listed above.

To test for the influence of the foreign exchange interventions on the USD/JPY exchange rate a multivariate GARCH model would be used following Chortareas, Jiang, Nankervis (2011). There will be a comparison of rolling estimations from three different data samples: 1991-2016, 1991-2000, 2001-2016.

Three different intervention regimes are observed during the studied period started in 1991 and ended in 2016 and there are two „dividing points" – 1995 and 2004. Univariate GARCH models obtained from three separated ranges of the time series as well as the whole data sample would provide the one with nuances of every different regime and answer two questions – if the time horizon of the Japan FX intervention is a short run and what type of intervention policy is the most effective one.

There are two main sources of data which are going to be used in the study:

- the USD/JPY exchange rate are closing spot prices by Investing.com;
- foreign exchange intervention operations by Ministry of Finance Japan.

Expected Contribution:

As it can be seen from the current economic environment, it is crucial for governments as well as central banks to manage currency in a careful and safe manner. One of the most recent papers on the topic is dated back to the year 2011, although MoF of Japan has conducted some interventions since that time, those interventions were excluded from the sample because they were conducted after the financial crisis 2008-2009. In this study, all the available information about the Japanese FX interventions is included into the data sample.

The possible contribution of the study can be that it would help to evaluate the effectiveness of different types of intervention regimes according to the target of BoJ and, what is more important, choose the most appropriate one in the current economic environment.

Outline:

1. Introduction (motivation, history of the Japan foreign exchange interventions and their results).
2. Analysis of the related literature (using of GARCH models in the academic papers which were focused on the volatility of the USD/JPY exchange rate and also examined the effect of the foreign exchange interventions on the volatility of the rate).
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5. Conclusion.

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Author **Supervisor**

1. Introduction

The present work is devoted to the analysis of such a problem as the effectiveness of foreign exchange interventions. Until recent times, interventions in the foreign exchange markets were probably the most secretive actions for the part of monetary authorities around the world. They have always been the cause of controversy, both in academia and among practitioners. Many economists, relying on known monetarist models of exchange rate formation, argue that interventions cannot be effective; It is also considered that the size of the foreign exchange market is infinitely large in comparison with the intervention operations, and thus neutrality arises. Others talk about efficiency in the sense that interventions affect course dynamics through the channel of expectations. Some models - the so-called portfolio models - consider changing the risk for securities nominated in different currencies as a decisive factor of the impact on the course through interventions. The dominance of these or other views on the effectiveness of foreign exchange interventions has changed over the past several decades. Due to the availability of official publicly available data from the MoF and the US Fed, there is a real opportunity to assess the effectiveness of foreign exchange interventions from a statistical point of view and to evaluate their impact on the dynamics of the exchange rate and the stability of the foreign exchange market.

After the US dollar and euro, Japanese yen is the third largest currency traded in the foreign exchange market. It is also often described by traders as a “safe heavens” currency.

Currency pair US dollar and Japanese yen, in particular, is traded on the highest volume compared to other pairs coupled with yen. Cyclical appreciation in tandem with global economic recessions is, therefore, expected of yen. To that effect, suspicion of seasonality in the time series is a grounded assumption. But most importantly, exchange rate policies, over the last three decades, have impacted the yen volatility more than any other factor.

There are two ways in which foreign exchange interventions can affect the market. Usually, the primary goal of the monetary authorities is to achieve a particular level of the exchange rate. Another possible target may be the reduction of the volatility of the exchange rate.

Most of the empirical studies which analyse the effectiveness of the foreign exchange interventions in Japan employ GARCH-like model specification as they are focused on the evaluation of time series and use officially released data by the MoF from the year 1991 till 2004. The problem is that all the variety of papers do not provide one with a coordinated and unequivocal opinion about the positive or negative effect which foreign exchange interventions have on the volatility of the dollar/yen exchange rate.

In our study, we apply one more advanced GARCH-like model extension which is called GARCH-in-mean to account for the influence of the volatility on the level of the exchange rate and to control for the relationship between risk and return which is important for the financial assets. On the other hand, we also include external independent variables which are supposed to control for the effect of the interventions themselves, coordination of the Japanese unilateral operations with the US Fed as well as market conditions.

The data sample is extended as we would like to have our analysis data driven so unlikely to most of the recent studies our full data sample includes a period from 1991 till 2011 when the last intervention was conducted by the MoF on behalf of the BoJ. The full data sample is divided into four subsamples which represent various intervention techniques used by the Japanese monetary authorities. We expect to have different results on the significance and values of estimated coefficients for the interventions depending on the frequency and scale to verify or reject the generalised findings of the latter studies.

In our study, we consider every intervention regime separately, so we do not conduct model estimation combining, for example, the first and the second regime or the second and the third one. On the one hand, it can lead us to the insignificance of the results, but at the same time, it provides us with the opportunity to assess pure differences in the intervention techniques of the BoJ. What is more, reverse causality problem is not addressed in our study, but in this problem, we will rely on the results of the previous studies, for example, Hillebrand and Schnabl (2006), who use reaction function to prove that changes in volatility do not trigger interventions, thus, simultaneity bias can be reasonably ruled out from our estimation.

As we use GARCH-in-mean model, we can obtain results both for the influence of the foreign exchange interventions both on the level and the volatility of the dollar/yen exchange rate.

Thus, our main finding is that so-called “appreciating” interventions when US dollars were sold, and Japanese yens were bought do not have any considerable effect neither on the level nor the volatility of the currency market for each of the subsamples. While the “depreciating” interventions have affected the volatility under the first and second intervention regime, although the values of the estimated coefficients are tiny and have opposite signs. Intervention operations tended to increase volatility under the second regime when interventions were not frequent but of a large scale and decrease it under the first regime when interventions were frequent but of the small scale.

The second important outcome is that under the regimes when the interventions alter the volatility of the dollar/yen exchange rate they were coordinated with the US Fed, so our finding regarding this supports the generalised results of the other researchers that only coordinated interventions seem to have an effect on the market stability.

Contrary to our expectations we have not found the intervention technique under the third regime to be successful regarding the effect on the volatility. During this period the foreign exchange market in Japan was mostly affected by the market conditions in the US. Almost the same result we have for the fourth regime when interventions were not conducted in a systematic way, so there were the only series of single operations.

As we can interpret our results the foreign exchange interventions have short-lived horizon so to achieve the goal – whether it is a particular level of the exchange rate or reduced volatility – all the operations have to be planned for the long-term as we observe it under the first and the second intervention regime. The single operation does not have a considerable effect which lasts longer than one day so to support the lasting trend, there should be planned and consistent tactics. Otherwise, as we are going to obtain the results from the third and the fourth subsamples when even the high amount of money injected into the economy cannot change the situation on the market stability.

The thesis is structured as follows: the next chapter reviews empirical papers which study the effectiveness of the foreign exchange interventions conducted by the Japanese monetary authorities. Chapter 3 provides the description of data which is used for the study and the methodology which is applied for the analysis. Chapter 4 is dedicated to the discussion of the results obtained from the estimation of the model. The final chapter summarises the most important outcomes and proposals.

2. Literature review

Although some studies are analysing the impact of central bank interventions on exchange rates in associated markets, they offer varied results. Contradictory outcomes confirm the existence of different types of intervention policies which have been used in various sample periods for exchange rate regimes of concrete structures. This section reviews the findings of authors who have studied the effects of foreign exchange interventions on the level and volatility of the yen exchange rate against the dollar.

Sterilised foreign exchange interventions were a subject of discussion on their capability to achieve a desired level of the exchange rate or reduce volatility. According to Rogoff (1984) in the portfolio balance models foreign and domestic assets are imperfect substitutes and, as a result, sterilised intervention can influence the exchange rate by changing the relative supplies and thereby the relative returns of foreign and domestic assets. According to Sarno and Taylor (2001), most of the papers from the past provide one with more evidence for the successful interventions; there are also conflicting results of the empirical studies on the effects of the foreign exchange rate intervention on the volatility as well as the level of the exchange rate.

Dominguez (1998) analyses the effects of foreign exchange interventions performed by central banks on the volatility of exchange rates. The data used in the study includes quite a wide time range - from 1977 to 1994. The data presented relates to mark/dollar and yen/dollar exchange rates and interventions by the US, German and Japanese central banks. According to the paper, there is no reverse causality effect between intervention policy and exchange rate volatility thus this volatility does not have an effect on the decisions of monetary policy makers. The author also studies public and secret interventions which could have opposite effects on volatility. To reduce the variance of the exchange rate an intervention should be announced publicly and, on the other hand, secret intervention often makes the volatility level increase. The main outcome from the full data sample is that the interventions that have been reported increase both short- and long-term exchange rate volatility. In contrast, in the sample from the mid-1980s, the variance is decreased by this type of monetary policy.

Beine, Laurent, and Lecourt (2001) employ a regime dependent approach in their paper which focuses on both level and volatility changes of exchange rates due to

the interventions performed. The data sample is 1985-1995 for the three most traded currencies of this historical period – mark/dollar and yen/dollar. In contrast to the previous studies, the authors come to the conclusion that reducing the volatility effect of the intervention can be demonstrated, depending on the volatility regime which currently prevails in the foreign exchange market. If there is a highly volatile market and intervention is expected to be performed, then the intervention stabilises the market ("the signalling approach"). Also, the discrepancy in the effects of concerted and unilateral interventions is examined. It is argued that to have a larger stabilising effect the central bank (or other authority) should coordinate its actions with other market participants. Furthermore, intervention policy should be more transparent as the effect of it directly depends on the motivation and current state of the market.

Following this, there is a period of studies mostly restricted to the dollar/yen exchange rate. Ito (2002) analyses the effectiveness of interventions using regression analysis and a reaction function approach. The paper examines not only the effects of the intervention policy on the level or volatility of the respective exchange rate but also the profits obtained from capital gains (realised, not realised and interest rate differentials). Regarding income, Japanese monetary policy is evaluated as successful and aiming to stabilise the market. However, interventions are claimed as being effective only in the second part of the 1990s. What is more, unilateral interventions independently performed by the Japanese monetary authorities are found to be considerably less effective than those coordinated with the US interventions.

There are also some papers continuing in the analysis of foreign exchange interventions. For instance, Hutchison, Fatum (2003) employ event study methodology, particularly, non-parametric sign and matched sample tests. Most of the studies published in the 2000s are focused on data sample from 1990 to 2000. The authors come to the conclusion that sterilised interventions have a stabilising effect on the exchange rate in the short run. Regarding large scale interventions coordinated with the US Fed, it is again confirmed that they are among the more effective and successful ones. Also, there is no necessity to support the intervention policy with an appropriate interest rate policy. This paper also focuses on interventions as a "signal" tool used by the enabled authorities to communicate to market participants their concept of the equilibrium level of the exchange rate.

According to Nagayasu (2004), foreign exchange interventions performed by the BoJ are ineffective if they are not concerted with the Fed. The author employs different specifications of the GARCH model, and in the results reported Japanese unilateral interventions are statistically insignificant. At the same time, concerted

interventions are said to be effective in affecting the level of the exchange rate. What is more, interventions have a short-term effect on the movements of the dollar/yen exchange rate in the sample period, which lasts only a day. The models which are specified in the paper provide evidence for an increasing effect of intervention policy on exchange rate volatility. It can be interpreted to mean that interventions lead to an increase in the uncertainty of the market.

In Chaboud and Humpage (2005) concentrated mostly on the short-term effectiveness of interventions performed by the BoJ in 1991-2004. The whole sample data is barely sufficient to predict shifts in the exchange rate level. But, as has been mentioned and demonstrated in previous papers, to be effective Japanese intervention should be aligned with the US intervention. The effect of interventions conducted by the Japanese authority alone is defined as moderate but detectable with a short run effect on the variance of the dollar-yen exchange rate. For the second part of the data sample, where interventions are less frequent than in the early 1990s but greater in amount, this monetary policy tool is seen to be more successful.

Beine, Szafarz (2006) examine the impact as well as the effectiveness of foreign exchange interventions using standard GARCH (1,1) methodology. According to the study results, isolated intervention policy should be carried out on a large scale. Otherwise, the desired effects will not be achieved, and in some cases, the exchange rate volatility can be adversely affected. As a consequence, it is recommended that large-scale intervention policy is applied preferentially by the BoJ.

The level and volatility of exchange rates is also an object of the paper by Watanabe and Harada (2006) based on the means of the component GARCH model. The authors use data on the yen/dollar in the sample period of 1991-2003. The study reveals opposite effects of intervention: it reduces the volatility in the short-run in the second half of the sample, that is, the late 1990s, and has no effect on volatility in the first half of the sample. Supplementing what has been stated by previous papers, in this second half of the sample the BoJ's intervention can be seen as successful only in cases of policy coordinated with the US Fed.

Using the classical GARCH approach Hillebrand, Schnabl (2006) study the effects which interventions have on the volatility of exchange rates. The data sample is similar to that commonly used by the papers of this period – 1991-2004. In this case, the GARCH estimates are evaluated by the authors as "inconclusive". Also, some estimates on different reduced samples of data were performed and the existence of a "structural break" was confirmed, as around the year 2000, foreign

exchange interventions performed by the BoJ remained unsterilized due to the liquidity trap. The volatility of the yen/dollar exchange rate was increased by intervention policy during the whole of the 1990s. But in 1997 the situation changed, and interventions stabilised the market. On the other hand, the authors find no evidence of policy shift to large-scale interventions from small ones having any significant effect on volatility.

In 2007 in his paper Beine, using Japanese data tries to find reasons for central banks to apply secret foreign exchange interventions. Thus, according to the results of his study, the BoJ intervenes secretly when it aims to reduce exchange rate volatility or to achieve a certain level of the exchange rate on the market. Furthermore, a noise trading strategy has not been demonstrated, which could mean that secret intervention are used by the BoJ only to cause fundamental changes in the level or volatility of the yen/dollar exchange rate on the market.

Suardi (2008) employs a double threshold GARCH method to determine differences in regimes of the yen/dollar exchange rates. According to the outcomes of the study, the effectiveness of foreign exchange intervention depends on the current regime of the exchange rate. If the intervention is found to be effective, it is successful in decreasing the volatility of the exchange rate as well as changing the level of the exchange rate, especially if the model specified is non-linear with the exchange rate. Interventions are also found to be more effective when yen is massively depreciated against dollar. Furthermore, coordinated interventions of the BoJ and the Fed are more effective in reducing volatility which is demonstrated by the non-linear threshold model. The author indicates important practical applications, such as the necessity of agreement between policy makers and market agents on the desired level of the exchange rate. Secondly, another crucial factor is the similarity of the expectations of market agents on the direction and magnitude of the exchange rate movement needed to reach equilibrium. Thirdly, the effect of an intervention can be offset by asymmetric responses in exchange rate volatility.

Fatum (2010) analyses not only the effectiveness of interventions but also the distribution channels through which they can influence the level of the exchange rate or its volatility. In a time horizon of a day, actual intervention has a strong effect on the exchange rate, and it does not matter if market participants were aware of this intervention or not. In contrast to some previous papers, the portfolio distribution channel is seen to be one with the most considerable influence, while the signalling channel cannot be called effective. It is also important to understand what it means for market participants “to be aware of the intervention”. The authors come to the conclusion that most of the official statements which should provide information about

forthcoming interventions are inadequate. As a consequence, the announcement or non-announcement of intervention cannot affect the market to any considerable degree.

Dukich, Kim, and Lin (2010) evaluate the performance of the GARCH models for modelling daily changes in logarithmic exchange rates. They consider three exchange rate series – pound/dollar, yen/dollar, euro/dollar. For each sequence, the authors fit three GARCH models, with varying numbers of parameters, and attempt to replicate the empirical sequence via simulation. GARCH (1,1), GARCH (1,2), GARCH (2,1) models are used, and then the adequacy of each model is assessed. The tests of model adequacy are performed by simulating each GARCH model and comparing it to the corresponding empirical sequence. None of the GARCH models considered in the analysis captures the empirical nature of the exchange rate series particularly well; each model failed to adequately reproduce the sudden shift in variability associated with the financial crisis. Moreover, histograms of the residuals show mixed results. Residuals for the yen/dollar sequence appear to be slightly heavier-tailed or skewed left. Thus, while each sequence satisfies the assumptions underlying the GARCH model, the GARCH model does not appear to reflect the empirical nature of those sequences faithfully.

Chortareas, Jiang, and Nankervis (2011) analyse the effects of the BoJ interventions on exchange rate volatility using data not only on exchange rates dollar/yen and euro/yen but also intervention data on a daily and intraday basis. The econometrics methods they employ are diverse – multivariate GARCH models, quartile plots, and equal variance test. According to the paper volatility of the dollar/yen exchange rate is decreased by intervention policy, although in a "very" short-term and unstable manner. The spillover effect is also a very important object of the study. Thus interventions which decrease volatility on the dollar/yen market increase volatility on the euro/yen market. What is more, this revealed impact has a whole day effect. The authors also provide information on the effect that foreign exchange intervention has on the covariance of exchange rates. This is one of the pieces of evidence regarding the spillover effect between two markets – dollar/yen and euro/yen markets, which can have practical implications to balance investment portfolios. Following this, there are different effects of the intervention on volatility depending on varying market conditions. Regarding the heteroskedasticity of the intraday returns, the intervention policy of the MoF has positive effects, as it makes these returns more homoscedastic.

MacDonald and Mao (2016) study the yen/dollar exchange rate also by separating the whole data sample from 1991 until 2004 into three regimes using the

common dividing points – the year 1995 and 2003. The paper is aiming to analyse the relations between the foreign exchange interventions, speculation and sentiments and exchange rate movements. First, Ito's findings (2005) are confirmed, and the Japanese monetary authorities reacted by the interventions to the sharp appreciation of yen, exchange rate volatility and increasing speculation on the appreciation of the national currency. It is also pointed out that not only monetary policy plays an important role in the dynamic of the exchange rate but also the fundamental factors and market conditions. What is more, the authors identify important features of the successful monetary policy makers. Thus, for the clear and effective signalling interventions should be frequent and constant. Following this, for the effective coordination channel, the policy maker should intervene according to the expectations of the market participants. Thirdly, in the case of Japan, it is important for the MoF/the BoJ to consider "the behaviour and sentiment of currency speculators", particularly, the dynamics of the bond markets.

Studies of the period after the year 2001 are agreed on the effectiveness of large, coordinated and infrequent foreign exchange interventions. In contrast to this, there are opposite results for the effect which foreign exchange interventions have on the volatility of the exchange rate. The effect of foreign exchange interventions is found to be short-run, lasting no longer than one day. In the case of Japan, intervention policy cannot be considered as a signalling channel for changes in monetary policy.

Most of the studies conducted after the year 2001 when the official data on the interventions was published use the same data. As a result, the way in which full data sample is divided into the subsamples and the employed methodology are the main reason for the conflicting outcomes of these papers.

Thus, all the studies which apply GARCH-like specifications to study the effect of the foreign exchange interventions on the dollar/yen exchange rate can be divided into two groups – ones, which demonstrate effectiveness, and others, which demonstrates ineffectiveness. A more detailed overview is presented in the Appendix A. Outcomes also depend on the fact if each intervention regime is considered separately or if some of them are taken combined.

One innovation of this study is that it is supposed to be data were driven which means that the data sample is going to be extended until the year 2011. Overview of the related literature demonstrates the majority of studies focusing on the period from 1991 to 2004 when the Japanese monetary authorities intervened the foreign exchange market actively. Then a period of silence started when there were no noticeable actions

from the side of the BoJ and the Ministry of Finance. It can be identified as a possible reason why most of the researchers do not take this period into account when analysing intervention policy in Japan and its effect on the level of the dollar/yen exchange rate and its volatility. We will make an attempt to include all the available data on the interventions in the GARCH-in-mean model which is planned to be used for the analysis. The period from 2005 to 2011 (the MoF conducted the last intervention on November 4, 2011) is also interesting object to examine as at least two noticeable events took place there – financial crisis of 2008 and Tohoku earthquake and tsunami in March 2011. If we find no considerable effect of the interventions on the volatility under this subsample, then we will try to analyse separate effect of each intervention on the level of the exchange rate – if a target was achieved in both short- and long-term horizon.

The second feature of the study is that it focuses on the effectiveness of different intervention regimes employed by the Japanese monetary authorities. We run the model on the four subsamples to find which intervention technique can be considered as the most effective for reducing the volatility of the dollar/yen exchange rate. The main purpose is to identify some potential practical implications of the study which can be applied by the monetary policy maker mainly targeting to ease the exchange rate volatility.

Another innovation of our study is that we will use a GARCH-in-mean modification of the classical GARCH-model. After completing the review of the existing empirical studies, we have not found that this type of GARCH-model extension has been already used for the analysis of the effect of the foreign exchange interventions on the both level and volatility of the dollar/yen exchange rate. Application of GARCH-in-mean model will allow us to account for the effect of the conditional variance on the conditional mean. This is a very important feature of the financial assets when the returns heavily depend on the risk. Thus, in case a coefficient of the conditional variance in a mean equation will be significant under one or more intervention regimes, we will be able to conclude that the level of the exchange rate is determined by the volatility than any other external controlling variable, included in the equations.

3. Data and Methods

3.1. Data description

The data on the dollar/yen exchange rate are closing spot prices. The observation period is from January 2, 1991, up to December 30, 2011. The choice of the data sample is based on the availability of official information on foreign exchange intervention operations conducted by the MoF on behalf of the BoJ. According to historical data which is currently available in the public domain, the first intervention was performed on May 13, 1991, and the last on November 4, 2011. In our full data sample, we try to capture all the intervention data.

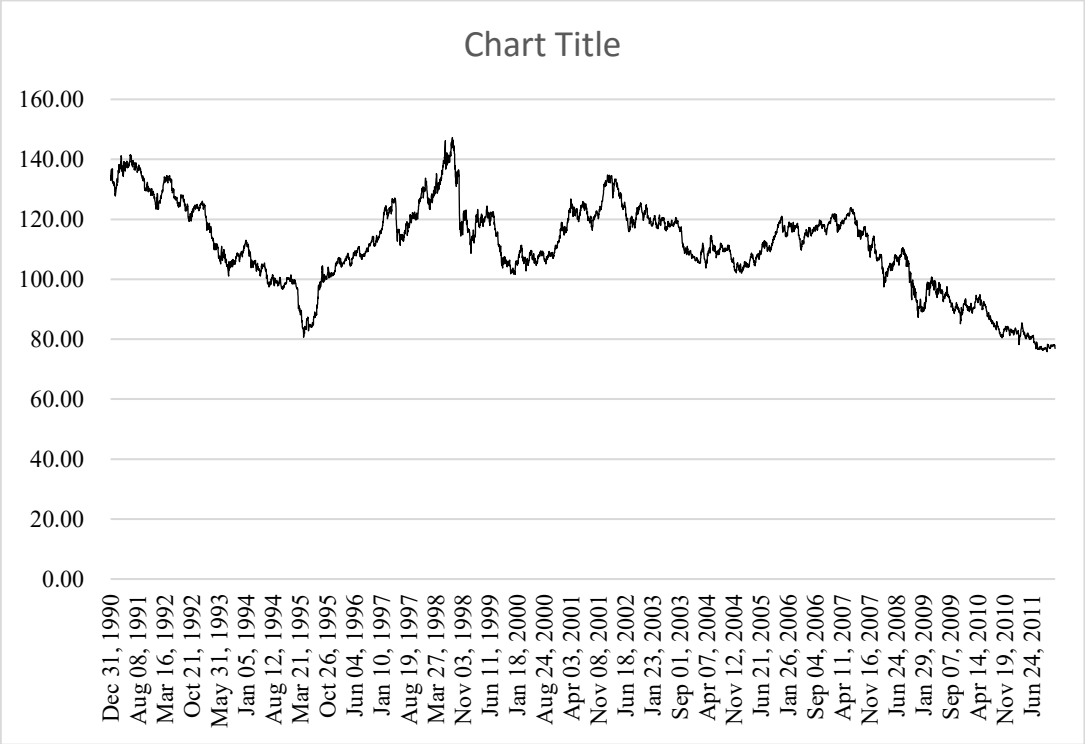

Figure 3.1: Daily Dollar/Yen Exchange Rate, 1991-2011

Source: Investing.com.

The nominal dollar/yen exchange rate does not show either substantial appreciation or depreciation. As can be seen from the Figure 3.1 there are certain periods of yen appreciation – from 1991 till mid-1995 and from 2007 till the end of the sample. At the same time, one can also see certain periods of yen depreciation, which took place from the middle of 1995 till 1998.

The intervention data sample includes 376 observations. The unit size is 100 million yen. Foreign exchange interventions by the BoJ can be divided into different types according to the pairs of currencies that were bought or sold respectively:

1. US dollar bought, Japanese yen sold;
2. Japanese yen bought, US dollar sold;
3. Deutsche Mark bought, US dollar sold;
4. Deutsche Mark bought, Japanese yen sold;
5. Indonesian rupiah bought, US dollar sold;
6. Euro bought, Japanese yen sold.

Starting from May 13, 1991, till November 4, 2011, the MoF intervened in the foreign exchange market 376 times. Almost all the intervention operations relate to the pair the dollar/yen of a total amount equalling 74 944,3 billion yen on 351 days with an average size of 213,52 billion yen. This volume accounts for 93% of all the intervention operations with yen.

As operations on Deutsche mark and Indonesian rupiah cannot be recognised as a systematic approach by the BoJ, we concentrate only on those foreign exchange interventions triggering dollar/yen exchange rate and euro/yen exchange rate as the source of spillover effect between two markets. Out of 5 473 trading days, the MoF reports 351 "dollar" intervention days – 319 dollar purchases and 32 dollar sales.

Table 3.1: Overview of Japanese Foreign Exchange Interventions, May 1991 – November 2011

		Selling yen, purchasing dollar (weakening yen)	Purchasing yen, selling dollar (strengthening yen)	Selling yen, purchasing euro
Absolute amount, 100 million	yen	798 237,00	48 794,00	10 753,00
Number intervention (per month)	of days	319	32	18
Average 100 million	size,	2 502,31	1 524,81	597,39

As proposed by Ito (2003; 2007) the period from 1991 till 2004 is divided into three regimes. Two dividing points can be identified according to board changes which relate to policy makers. Thus Eisuke Sakakibara took office as Director-General of the

MoF's International Finance Bureau in June 1995 and Zenbei Mizoguchi as Vice-Minister of Finance for International Affairs in January 2003.

Figure 3.2 represents differences between the intervention regimes mentioned above.

1. January 2, 1991 – May 31, 1995: frequent small-scale interventions (first regime);
2. June 1, 1995 – December 31, 2002: infrequent large-scale interventions (second regime);
3. January 1, 2003 – March 31, 2004: frequent large-scale interventions (third regime).

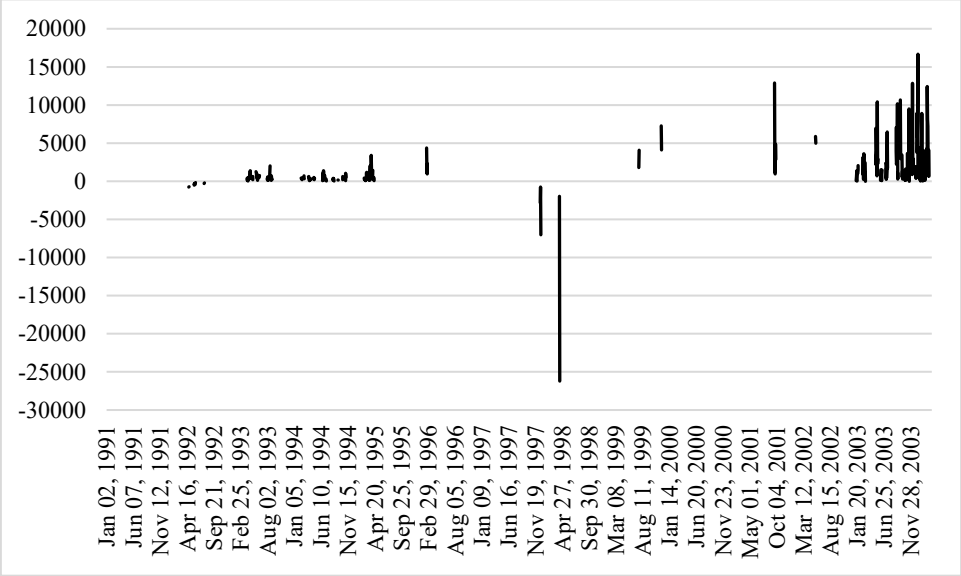

Figure 3.2: Absolute Foreign Exchange Interventions, 1991 – 2004

Source: the MoF.

The remaining part of the full data sample from April 1, 2004, till December 30, 2011, is treated as a fourth regime although this time frame is not included in most of the studies published after 2010, as this data is affected by the consequences of the financial crisis.

From Figures 3.1 and 3.2, we can observe that the purchase of the yen occurred during periods of its depreciation, sales - during periods of its strengthening. There were also points when there were sales of the yen against the background of its depreciation; this suggests that the BoJ conducted interventions to retain or even accelerate the emerging dynamics of the course. In general, the periods of the sale of the yen were accompanied by a further fall in its value. Only one period is

characteristically distinguished against this pattern. The last years of the sample: the largest in the history of the 1990s currency interventions occur against the background of the strengthening of the yen, and there is no change in this trend, suggesting whether the use of this tool is effective at all.

Figures 3.1 and 3.2 indicate one more interesting feature of the movement of the yen. Fluctuations of the course throughout the considered gap occur around the average value (about 115 yen per dollar) with the tendency of damping of the oscillations towards the end of the sample. This trend may mean that the market, in the long run, seeks to establish some, say, its equilibrium, the level of the price of the yen. This fact can be useful when choosing a yen rate movement model, for example, an error correction model with control parameters in the form of currency interventions can be constructed.

According to Takagi (2014) intervention policy in Japan has not been created by the BoJ as a monetary authority. The intervention decisions are said to be made "by a small group of MOF officials that includes the Minister of Finance, the Vice Minister for International Affairs, the Director-General of the International Bureau (…), and several other line officers". Thus, the BoJ is just executing transmitted decisions, and its role is not crucial. It cannot be said that Japanese intervention policy is the product of the BoJ alone, it is correct to consider it as a joint activity of the MoF and the BoJ.

A shift from the first to the second regime is observed after the appointment of Sakakibara as Director General on June 21, 1995, when the technique changed from small and frequent operations to less frequent but greater ones. The aim was to keep the dollar/yen exchange rate at a certain level, and this considerable change in intervention policy was considered as a possible channel to "surprise" market agents.

In 2003 there came the regime of the "great intervention" (Taylor, 2006) after Mizoguchi started as Vice Minister on January 14, 2003. The yen was appreciating while the Japanese economy was in the so-called "deflation trap" (Mizoguchi, 2004) so according to the information provided by the Ministry of Finance over a short period from January 2003 to March 2004, 35 trillion yen were sold to weaken the Japanese national currency. These operations were supported by the simultaneous expansion of the monetary base by 15 trillion yen, which makes it possible to consider them as "partially unsterilized".

According to Ito (2004), there are two most important reasons for the monetary authorities to conduct intervention actions. The first one is a sharp appreciation or depreciation and the second one is a deviation from the long-term trend. On the other

hand, after January 2003 there were a great number of intervention operations which cannot be explained by these traditional reasons. Ito provides three other possible causes:

- preventing "premature" appreciation;
- purchasing foreign bonds as a means of expanding the monetary base;
- preventing speculative forces from moving the dollar/yen exchange rate.

The active period of the foreign exchange interventions in Japan was lasting until March 2004. In recent years, Japanese monetary authorities intervened only several times between September 15, 2010, and November 4, 2011, aiming to prevent the sharp appreciation of yen and its nontrivial volatility which were the consequences of Great East Japan earthquake in March 2011 (Bordo et al., 2012).

Appendix B represents comparison of the different intervention techniques for every regime separately with the level of the exchange rate and volatility. As a measure of volatility, we use the standard deviation of the daily logarithmic returns and there is no obvious simple relationship between volatility and interventions operations.

Table 3.2: Basic statistics of dollar/yen exchange rate

Statistic	Full data sample	Regime I	Regime II	Regime III	Regime IV
Number of observations	5 473	1 150	1 973	326	2 024
Mean	110.93	116.04	116.67	114.16	101.91
Standard deviation	14.57	15.27	11.17	5.34	13.62
Minimum	75.82	80.65	84.00	104.30	75.82
Maximum	147.26	141.55	147.26	121.46	123.87
Coefficient of variation	13.13	13.16	9.57	4.68	13.36
Start	02.01.1991	02.01.1991	01.06.1995	01.01.2003	01.04.2004
End	30.12.2011	31.05.1995	31.12.2002	31.03.2004	30.12.2011

Table 3.2 provides descriptive statistics of the dollar/yen exchange rate during the observation period. Following Fidrmuc and Horvath (2008) and using the coefficient of variation (standard deviation divided by the mean of the individual currency) it is possible to come to the conclusion that the Japanese yen is not a very stable currency. According to Fidrmuc and Horvath currencies which have a coefficient of variation of less than ten are characterised to be the most stable.

As the purpose of the study is to examine the volatility of the dollar/yen exchange rate using GARCH type models, we have to test whether our dataset is

stationary or not. As can be seen from Figure 3.1 it appears that the time-series are not stationary. We also use the autocorrelation function and partial autocorrelation function, and the ACF declines towards zero at a slow rate in time. The Portmanteau statistic is 182,503.7940 (0.0000), so we reject $H_0$of Portmanteau test that the AC coefficients are jointly insignificant. Then we can test the stationarity of the process with two unit root tests - Augmented Dickey-Fuller Test (ADF test) and the KPSS test.

1. The ADF test is based on models of the form:

$$\Delta y_t = \varphi y_{t-1} + \sum_{j=1}^{p-1} a *_j \Delta y_{t-1} + u_t \quad (3.1)$$

In this model the pair of hypothesis

$$H_0: \varphi = 0 \; versus \; H_1: \varphi < 0 \quad (3.2)$$

are tested based on the t-statistic of the coefficient φ from an OLS estimation of (2.1). $H_0$is rejected if the t-statistic is smaller than the relevant critical value. If φ=0 (that is, under H_0) the series y_t has a unit root and is non-stationary, whereas it is regarded as stationary if the null hypothesis is rejected.

2. The KPSS test is based on the null hypothesis of stationarity, and it is rejected for large values of KPSS statistics.

Table 3.3: Unit root tests of the time series on the daily dollar/yen exchange rate

	ADF test t-statistic (5% critical value)	KPSS test t-statistic (5% critical value)
Full data sample	-1.2252 (-1.94)	47.2876 (0.463)
1st regime	-2.0662 (-1.94)	36.2304 (0.463)
2nd regime	0.5435 (-1.94)	11.9981 (0.463)
3rd regime	-1.4802 (-1.94)	9.3036 (0.463)
Remained sample	-1.0106 (-1.94)	52.1021 (0.463)

We cannot reject the null hypothesis of non-stationarity for the augmented Dickey and Fuller test if the t-statistic is greater than the critical value at 5% confidence level. But at the same time, we should reject the null hypothesis of stationarity for the KPSS test if the t-statistic is greater than the critical value. So, from Table 3.3 we can say that our full data sample, as well as four subsamples of the dollar/yen exchange rates, is non-stationary. There is a deviation in the first regime where the t-statistic is

smaller than the critical value, but the stationarity of this subsample is not confirmed by the value of the t-statistic from the KPSS test as well as by the time series plot and partial autocorrelation function.

Because we can apply GARCH models only to stationary processes, we have to transform the daily dollar/yen exchange rate using the logarithm of the first differences. According to Strong (1992) "there are both theoretical and empirical reasons for preferring logarithmic returns. Theoretically, logarithmic returns are analytically more tractable when linking together sub-period returns to form returns over the long intervals. Empirically, logarithmic returns are more likely to be normally distributed and so conform to the assumptions of the standard statistical techniques." If x_t is the exchange rate at time t, we transform the sequence the of exchange rate as follows:

$$y_t = \log\left(\frac{x_t}{x_{t-1}}\right) = \log x_t - \log x_{t-1} \tag{2.3}$$

where y_t is known as the log difference of x_t at time t.

Having transformed the time-series, we can test it for stationarity using the same tests – ADF and KPSS.

Table 3.4: Unit root tests of the time series on the daily dollar/yen exchange returns

	ADF test t-statistic (5% critical value)	KPSS test t-statistic (5% critical value)
Full data sample	-43.6424 (-1.94)	0.1087 (0.463)
Regime I	-21.4762 (-1.94)	0.1351 (0.463)
Regime II	-25.4519 (-1.94)	0.2918 (0.463)
Regime III	-9.1082 (-1.94)	0.1365 (0.463)
Regime IV	-26.7115 (-1.94)	0.2436 (0.463)

Table 3.4 confirms the fact that the transformed time series of the full sample, as well as four subsamples, are now stationary and there are no unit roots.

Table 3.5: Basic statistics of the daily dollar/yen returns

Statistic	Full data sample	First regime	Second regime	Third regime	Fourth sample
Number of observations	5 473	1 150	1 973	326	2 024
Mean	-0.0001	-0.0004	0.0002	-0.0004	-0.0002
Standard deviation	0.0071	0.0067	0.0075	0.0051	0.0071
Kurtosis	5.0129	3.4128	6.5202	0.8359	0.0640
Skewness	0.1217	-0.2740	-0.7648	0.1168	0.0885
Minimum	-0.0695	-0.0337	-0.0695	-0.0161	-0.0363
Maximum	0.0522	0.0406	0.0380	0.0176	0.0522
Range	0.1217	0.0743	0.1075	0.0337	0.0885
Start	02.01.1991	02.01.1991	01.06.1995	01.01.2003	01.04.2004
End	30.12.2011	31.05.1995	31.12.2002	31.03.2004	30.12.2011

Table 3.5 presents the descriptive statistics of daily returns dollar/yen for the whole data sample as well as four intervention regimes. The mean values of returns are very close to zero while the standard deviation is approximately 0.007 with insignificant differences. Second intervention regime can be considered as the most volatile one as it has the highest standard deviation level.

For our analysis, we also include external independent variables in the mean equation and the variance equation to estimate the effect of the interventions on the level of the exchange rate and its volatility respectively.

Two most important variables are the interventions which were conducted by the BoJ during the examining data sample. For the analysis, we divide them into two groups:

- interventions which were aiming to appreciate yen, it means that the BoJ bought Japanese yens and sold the US dollars;
- interventions which were aiming to depreciate yen, it means that the BoJ sold Japanese yens and bought the US dollar.

Unlike other instruments of monetary and monetary policy, data on which are published on a regular basis in almost all countries, the information on the currency interventions of the BoJ was closed until 2004. It should be noted that even now not all countries publish the relevant statistics: The Fed and the US Treasury, the Bank of Canada, the MoF are examples of the openness of the actions of monetary authorities. Data for intervention in Japan, USA were available for this study.

In general, the BoJ directed interventions against the strengthening of the yen. First, the interventions of the early 1990s were significantly smaller regarding the volume of interventions in the late 1990s, and secondly, except certain periods of intervention, are clustered; thirdly, Appendix B clearly shows the variability in the variance over time, which is characteristic for financial variables.

Table 3.6: Basic statistics of the "depreciating" interventions

Statistic	Full data sample	First regime	Second regime	Third regime	Fourth regime
Number of observations	319	139	43	129	8
Mean	2,502.31	501.77	4,964.95	2,719.21	20,527.50
Standard deviation	5,838.82	438.78	3,523.96	3,010.68	28,555.18
Kurtosis	110.03	14.19	0.57	4.72	2.29
Skewness	9.15	2.96	0.90	2.06	1.70
Minimum	1.00	51.00	430.00	1.00	2,028.00
Maximum	80,722.00	3,388.00	14,059.00	16,664.00	80,772.00

Following Hillebrand and Schnabl (2006) to control for disturbances in other asset markets, we include daily log returns of Japanese and US stock indices, the Nikkei 225 for Japan and the Dow Jones Industrial Average for the US, both provided by Yahoo!Finance. The US foreign exchange intervention data are provided by the Federal Reserve Board and are sub-divided into yen, mark, and other currencies purchased or sold. Following the same logic as we do for the case of the foreign exchange interventions conducted by the BoJ we include only 23 intervention operations which affect Japanese yen in our data sample.

Our analysis is data driven, so we synchronise all the data with the dates on which the information on the dollar/yen exchange rate is available. For the appreciating interventions, we use negative values of the Japanese yen bought as the BoJ has extracted this volume of money from the economy. Contrary to this for the depreciating interventions, we use positive values of the Japanese yen sold as the BoJ has injected this amount of money to the economy. If there was no intervention on a certain date, then we took the value of zero as the official data are available on the webpage of the Ministry of Finance of Japan. For the missing data in the Nikkei and Dow Jones indices, we use the data available for the previous day following Cooper and Finkelstein (2016).

3.2. Model description

The efficiency of the foreign exchange interventions can be considered as:

- the possibility to have any effect on the dynamics of the level of the exchange rate expressed in certain quantitative units;
- the possibility to influence the stability of the currency market expressed in certain quantitative units.

The reason for choosing these criteria of effectiveness is based on the arguments that the monetary authorities give in favour of interventions. If interventions are effective, the monetary authorities use these instruments reasonably; otherwise, it is either waste of resources or an attempt to make money by currency speculation under the guise of certain political promises.

According to Dominguez (1998), interventions can be recognised as the successful one if the volatility is reduced and the volatility is determined by squared returns.

The choice of the GARCH-in-mean model is also motivated by the fact that in the case of the risk of the financial asset and the expected return are correlated. To account for this relationship, it makes sense to include in the mean equation the conditional estimated variance. As a result, we are aiming to investigate not only how both the level of the exchange rate and the volatility are affected by the foreign exchange interventions but also how the risk influences the return. It will also help to control for one more variable in the mean equation.

After the preliminary investigation of the full data sample and all the four data subsamples, we can initiate the actual estimation of the parameters of the GARCH-in-mean model for the full data sample as well as subsamples. The GARCH-in-mean model was introduced and developed by Engle, Lilien, and Robins (1987), it is based on the GARCH(1,1) model introduced by Bollerslev (1986, pp. 307-327), and it consists of two equations, one for the mean and another one for the variance of the time series.

As it has been stated in the Data Description section, Japanese intervention policy has been concentrated mainly on the dollar/yen currency market. 93.35% of interventions (regarding a number of operations) is against US dollar, so all the other exchange rates coupled with yen are excluded from the model specification.

The specification the ARCH-in-mean model allows the mean of a time series to depend on its own conditional variance. This type of model is defined as a very useful one in modelling asset returns. According to the theory of optimal portfolio choice, the mean of a risky asset return should depend on its variance. A simple AR(1) – ARCH(1)-in-mean model can be written as follows:

$$y_t = a_0 + a_1 y_{t-1} + \delta h_t + \varepsilon_t \tag{3.3}$$

$$h_t = E_{t-1}[\varepsilon_t^2] = \alpha_0 + \alpha_1 \varepsilon_{t-i}^2$$

An ARMA – GARCH generalisation of this simple model is also possible.

For analysis, we will use a variation of this extension, and the model takes the following form:

$$\Delta s_i = \mu + archm \cdot \sigma_i^2 + \varepsilon_i + b \cdot BUY_i + s \cdot SELL_i + \\ + c \cdot COORDINATION_i + n \cdot NIKKEI_i + d \cdot DOW\ JONES_i \tag{3.4}$$

$$\sigma_i^2 = \omega + \alpha \cdot \varepsilon_{i-1}^2 + \beta \cdot \sigma_{i-1}^2 + \gamma \cdot \ln \sigma_{i-1}^2 + b \cdot BUY_i + s \cdot SELL_i + \\ c \cdot COORDINATION_i + n \cdot NIKKEI_i + d \cdot DOW\ JONES_i$$

where Δs_i is the difference of the log of the exchange rate between time *t* and *t-1* (exchange rate over two consecutive trading days);

the conditional variance in the mean equation (σ_i^2) allows for the effect of the observed volatility on the level of the exchange rate;

ε_i are the residuals;

BUY_i are the interventions which the BoJ conducted aiming to appreciate yen, so it bought Japanese yens and sold US dollars;

$SELL_i$ are the interventions which the BoJ conducted aiming to depreciate yen, so it sold Japanese yens and bought US dollars;

$COORDINATION_i$ is a dummy variable which reflects the fact if at the same trading day there was an intervention conducted by US Fed to support a monetary policy of the BoJ. In case an operation took place, $COORDINATION_i$ equals 1, otherwise – 0.

NIKKEI$_i$ is daily log returns of the of the Nikkei 225, a stock market index for the Tokyo Stock Exchange (TSE). This variable is included in the model to account for the situation on the Japanese stock market as well as for the economic situation in Japan on the whole.

DOW JONES$_i$ are daily log returns of Dow Jones Industrial Average, and it is included in the model to account for the situation on the American stock market as Japanese economy depends in many ways on the export of goods to the United States.

The initial GARCH model implies non-negativity of the values of the included variables. Thus, this formulation automatically involves the insignificance of the direction (sign) of intervention for the stability of the currency market, which may be incorrect. In GARCH theory, this possibility was taken into account by developing an exponential model of E-GARCH, where, firstly, the non-negativity of the vector of exogenous variables is no longer required, and, secondly, the asymmetry of the residuals is taken into account.

Various ARIMA models were fitted to the data and the one with the lowest BIC selected (results are presented in Appendix C). Using the residuals of the ARIMA models of the most suitable order respectively for every intervention regime we then test for ARCH effects. Because of the small p-values we can reject the null hypothesis and conclude that there are ARCH effects, thereby justifying the of the GARCH-type models.

Table 3.7: Results of Box-Ljung test for ARCH effect in residuals

	Regime I	Regime II	Regime III	Regime IV
Chi-squared	39.3	119.93	13.262	574.04
df	12	12	12	12
p-value	9.391e-05	<2.2e-16	0.3503	<2.2e-16

As it can be seen from the Table 3.7 p-value is rather high for the Regime III so for this subsample we will regress the returns on the error term assuming that the exchange rate follows a random walk.

4. Discussion of the results

In February of 1973, the floating exchange regime was set up in Japan, and immediately after this Japanese economy faced the substantial fluctuations of the level of the exchange rate and formation of the long-term increasing trend yen to the US dollar and other European currencies. For levelling out the negative influence of the exchange rate fluctuations on the economy the BoJ started to carry out foreign exchange interventions, and information on this used to appear in media from time to time. According to the law about "The Bank of Japan" the foreign exchange interventions should be conducted for stabilisation of the level of the exchange rate, and they should be planned for the long-term period. Quite often there can be sharp fluctuations of the exchange rate on the currency market, which may have adverse consequences for the economy, and in this case, the particular unit of the BoJ is urgently associated with the MoF and conducts emergency interventions.

For stimulation of the Japanese economy, the BoJ adhered to the strategy of the "cheap" yen, which allowed to increase the volume of export and restrain the growth of import, what, undoubtedly, had a positive effect on the trade balance and GDP of Japan. From the year 2000 till 2010 Japan used to have positive trade balance, meaning that export had been dominating import considerably. From the year 2000 to 2007 trade balance increased by 76.39%, resulting in 4.889% of GDP in 2007 contrary to 2.56% in 2000. These data demonstrate the significant role of exports in the formation of GDP, and the depreciation of yen contributed a lot to that. During the period from 2008 till 2010 the real yen exchange rate against the US dollar decreased by 14.62%. The beginning of the crisis was marked by a fall in the rates of almost all the world currencies, except the yen, which for the period from September 2008 to September 2010 increased by 22%. The strengthening of the yen was smooth and systematic, with rare attempts to reverse the trend in March-April 2009 and April-May 2010.

Foreign investors perceive the Japanese economy as more stable than the US economy. Also, the current account surplus and the inflow of foreign capital due to a stable percentage differential for assets denominated in the yen contributes to the appreciation of the Japanese currency against euro and the US dollar.

There can be both positive and negative consequences of appreciation of the national currency (Table 4.1).

Table 4.1: Consequences of appreciation of the national currency

Positive features of the Japanese yen's appreciation	Negative features of the Japanese yen's appreciation
1. The slowdown in the growth of prices for goods and fuel.	1. The growth of imports.
2. Reorientation of exporting companies to domestic demand.	2. Reduction in the volume of exports of goods and technology, as a result - a reduction in GDP growth.
3. Optimisation of costs by exporting companies to reduce losses.	3. Reducing the profits of export corporations when they are received from abroad.
4. Reduction of the interest rate for correcting the difference for foreign assets, as well as for increasing consumer and investment costs.	4. Decreased competitiveness of goods in foreign markets (loss of markets).
5. The inflow of short-term foreign capital.	5. High risks of currency volatility due to the excessive inflow of speculative foreign capital. 6. Transfer of production to countries with weak currencies.

With the onset of the crisis in 2008, the current account balance decreased by 25.53%, and this trend continued in the following years.

According to Yasu and Shiraki (2010) in 2010 the share of foreign trade in the GDP structure has decreased to a minimum since 2002. Significant losses are borne by Japanese exporting manufacturers. Sony Corporation, which receives 70% of revenues outside of Japan, loses about 7 billion yen of operating profit annually due to the appreciation of the yen against the euro and 2 billion yen due to the weakening of the dollar against the Japanese currency. Over the years 2010-2011, Sony has closed 11 plants abroad, 20,000 jobs have been cut. Panasonic reduced nearly 30,000 jobs in 2010-2011 to minimise costs. Obviously, for the Japanese economy, strengthening the yen's exchange rate is a significant problem, so changing the trend is a priority goal for the economy to exit the recession.

At the same time, there are opponents of the depreciation of the yen. The main ones are Japan's trading partners: USA, EU, China, as well as competitors. Thus, in the United States in the period from 2000 to 2007, there was a significant deterioration in the current account balance - the negative balance increased by 74%. With the onset of the crisis, the situation began to improve radically, and from 2007 to 2010, the negative balance decreased by 33%.

One of the reasons for the positive dynamics of the current account is the depreciation of the US dollar against the currencies of its main trading partners,

which makes export goods more attractive to buyers abroad, and reduces imports of goods and services.

Corporations from China, South Korea, EU countries, USA are also not interested in the changing of the situation in the Japanese foreign exchange market as they are competitors of Japanese manufacturers of electronic home appliances, gadgets, cars, and other goods.

In August 2010, the BoJ took monetary measures to combat the growing value of the yen. They were aimed at increasing liquidity in the money market. The BoJ announced an increase in lending to commercial banks by 10 trillion yens (117 billion US dollars), as well as 30 trillion yens, will be directed to the program of affordable lending to households and the business sector. Also, the government of Japan announced a package of incentive measures amounting to 920 billion yens. All these measures in aggregate were to increase the yen's offer in the market and create prerequisites for reducing its rate.

However, the market participants, unfortunately, did not react positively to these measures, and in almost a week the US dollar to yen rate reached a 15-year low, falling below the 83 mark.

All this has pushed the BoJ to more decisive measures - currency interventions. The countries of the European Union, the United States, Great Britain and Switzerland were notified in advance of the alleged actions. Using a proven "rumours" strategy, rumours of interventions from the beginning of September 2010 were launched. The intervention was conducted on September 15, 2010. The BoJ spent 23 billion dollars on foreign exchange operations, which is an insignificant part of the country's official reserves, which On July 1, 2010, there were 1,063,513 dollars.

In the short-term period, the goal of the intervention was not achieved, and the trend was not broken. This is not surprising since the BoJ is opposed by very strong opponents - not only the central banks of other states (not interested in depreciating the yen) but also speculators who can make good money in "muddy water".

The data from Appendix D show the values from the β_1, α, β and γ coefficients of GARCH-in-mean model for all the four regimes. It is important to mention that in all our estimates of the model we used the hypothesis that the errors are distributed according to Generalised error distribution. There are several conclusions that can be drawn from this table.

First, we can observe that the estimated coefficients of the model respect the requirement that (α+β) <1, which is a crucial condition for a mean reverting process. This enables us to conclude that conditional volatilities are mean reverting for all the four intervention regimes.

According to Kočenda and Černý (2015), the sum of both coefficients also tells us about the speed of convergence of the forecast of the conditional volatility to a steady state: the closer to one its value is, the slower the convergence. As we can observe it from the Appendix D under the second regime α+β=0,96 which is the highest value among all the other regimes and demonstrates the slowest convergence to the steady state. Under the third regime we have a sum of α and β of 0,75, so during this period, the conditional variance was approaching its steady level with the higher speed than under both second and fourth regimes.

Second, we can observe that the estimated coefficients for the variance equation of the model (the α, β and γ coefficients) are statistically significant at the 95% confidence level only for the fourth intervention regime. For the first regime, the volatility is affected only by the logarithm of the lagged volatility which is also true for the second regime. For the second and the third intervention regimes, β coefficients are significant so we can conclude that only the lagged volatility affects the current volatility of the dollar/yen exchange rate.

The third conclusion is that the *archm* coefficient β_1 for the variance term in the mean equation is statistically significant only for the first intervention regime. This can potentially invalidate the initial hypothesis that there is a correlation between risk and expected return.

For interpretation of α and β coefficients, we will follow Kočenda and Černý (2015). Coefficient α reflects the impact of "news" of "surprises" from previous periods that affects the volatility of the dollar/yen exchange rate: a significant and positive α less than one depicts the extent of the shocks' effect on volatility, which is not destabilising. When α is greater than one then shocks materialising in the past are destabilising. According to our results, coefficient α is significant only under the fourth regime which leads us to the conclusion that under all the other regimes "news" and "surprises" from the previous day do not influence the current conditional volatility of the dollar/yen exchange rate. Thus, although under the first and second regime depreciating interventions have a considerable effect on the conditional volatility, changes in the volatility in preceding days, also caused by the intervention operations, were not able to increase or decrease volatility on the following day. Under the fourth

regime coefficient α has a negative value (-0.05), so we cannot determine unequivocally whether shocks do have or do not have a destabilising effect on the volatility of the dollar/yen exchange rate.

The GARCH term β, on the other hand, measures the impact of the forecast variance from previous periods of the current conditional variance, or volatility. A significant coefficient β (close to one) thus means a high degree of persistence in volatility. Contrary to the results that we have obtained for the estimated coefficient α, GARCH term β is significant, positive and less than one for the second, third and fourth regimes. It means that persistence in volatility plays the major role in the determination of the current level of the conditional variance for these three subsamples.

We can observe that depending on the type of the intervention regime different external independent variables have an effect on the level of the exchange rate. Thus, for the first regime which is characterised with infrequent and small scale interventions the level of the dollar/yen exchange rate is affected with conducting interventions targeting to depreciate yen (selling yens, buying US dollars), coordinated of the operations with US Fed and alteration of both Nikkei and Dow Jones indices. At the same time, the value of the estimated coefficient for "sell interventions" is so tiny so this external variable cannot be taken into account as a factor which determines the level of the dollar/yen exchange rate.

For the second regime, it is observable that level of the exchange rate is mostly affected by the situation on the US market as there are two significant regressors – interventions conducted at the same time by the US Fed and changing of the Dow Jones index. We can see that both estimates are positive, so it leads us to the conclusion that the growth of the US market results in an appreciation of yen as well as coordinated interventions augments the level of the dollar/yen exchange rate. As it is defined by the investigation of the first regime Nikkei index is also a significant external variable that also has negative value, which demonstrates that growth of the market decreases the level of the dollar/yen exchange rate.

Since BoJ had not conducted interventions which were targeting in appreciation of yen during third and fourth subsamples as well as there was no operation coordinated with US Fed we have excluded those two variables from the analysis. The third regime which is predicted to be the most efficient one regarding influencing the level of the exchange rate because of the frequent interventions of the great scale does not appear to support this prediction. As we can observe from the Appendix D there is no significant external variable affecting the level of the dollar/yen exchange rate. It is

important to mark that the value of the Nikkei coefficient is very close for the one from the third regime, in both cases values are negative.

We cannot call the fourth regime as a "regime" in a way that we used to do it with the three other ones because there was no chain of logical operations following each other on the entire data subsample. As a consequence, estimation results provide us with only two significant independent variables and one of them is daily log returns of stock market index – Dow Jones. Although depreciating interventions seem to be a significant factor by its value is zero.

According to the generalised results of relevant studies conducted by various economists after the year 2001 foreign exchange interventions of the BoJ are recognised as the effective ones for the second and third regimes when they are considered both separately and combined, as well as the for the entire data sample. On the other hand, under the first and the second regimes only coordinated interventions were effective. Our results partly support these outcomes. First, under both the first and the second regimes dummy variable for coordination of Japanese interventions with US Fed is significant and has positive value so we can conclude that only coordinated interventions were effective regarding changing the level of the dollar/yen exchange rate. At the same time, depreciating interventions (purchases of yens) were able to influence the level of the exchange rate under the first regime although the value of the coefficient is very tiny. This outcome also supports the general conclusion that yen sales are found to be more effective that the yen purchases regarding the effect on the level of the exchange rate.

There are some studies where the first regime was also recognised as the effective one for the alteration of the exchange rate level. Thus, for example, Ito (2003, 2005, 2007), as well as Watanabe and Harada (2006), have found both the first and the second intervention regimes to be successful in having an effect on the dollar/yen exchange rate, and the US interventions were more powerful that the Japanese unilateral interventions.

While the third regime was found to be successful for many types of research, we have the opposite result. In our model specification, the current level of the exchange rate is not affected by the external variables such as some the interventions or their coordination with the US Fed but by the conditional variance. The volatility of the exchange rate can be treated as a more important factor for the conditional mean that any other external regressor. When we include the conditional variance in the mean equation, we have started to control for the effect of the disturbance on the exchange

rate of yen against the US dollar, and at the same time, the other variables such as foreign exchange interventions have decreased their influence. There were no coordinated interventions under the last two regimes so we can conclude that the efficiency of the Japanese interventions was also reduced by their isolation.

There is also one important feature of the Japanese foreign exchange interventions – duration of their live time horizon. There can be a different way to solve the problem of simultaneity between intervention and exchange rate. Thus, Beine (2004) used dummy variables for lagged Japanese and US interventions for the period from April 1991 till October 2001. According to his results, the effect of the foreign exchange intervention is daily only, so the effective level of the exchange rate is determined by the current market conditions. Short-lived effect of interventions is also supported by the study of Beine et al. (2003) on the weekly exchange rate. The lagged intervention frequency did not affect the level of the exchange rate under the first intervention regime. In their studies, Kim (2007) and Kim and Le (2010) use intra-daily data to examine whether interventions have an effect which lasts longer than several hours or whether all the influence is dissolved during one trading day, and the short live impact is confirmed.

Further, we will discuss the results of our analysis of the effect of the foreign exchange interventions on the volatility of the dollar/yen exchange rate. Here we can observe a different situation (Appendix D), so the interventions influence the level and volatility of the exchange rate in various ways.

Interventions which are appreciating yen do not influence volatility as estimated coefficients are very small and not significant. On the other hand, depreciating interventions are found to be efficient for both the first and the second regimes, although the estimated coefficient is also slight and have a different sign (0.001 and -0.00003 respectively). We can observe a negative dependency between the volatility of the dollar/yen exchange rate and the depreciating interventions, which can be interpreted as the scenario that every 100 million of yen that have been sold decrease the volatility of the dollar/yen exchange rate by 0.00003 during the second regime. Contrary to the second regime infrequent depreciating interventions of the small scale tend to increase the volatility so in this way this policy cannot be claimed as the effective one. For both the first and second regimes coordinated interventions conducted by the US Fed have an increasing effect on the volatility of the dollar/yen exchange rate. Regarding the Nikkei 225 index, we can conclude that it has no considerable influence on the volatility for all the subsamples while estimated coefficient of the Dow Jones index is significant for the second and the third regime.

Thus, there is significant influence detected of individual interventions of the BoJ on market stability from the year 1995 till 2002. This fact can be interpreted as an indication that the monetary authorities of Japan were able to stabilise the market by their actions. This fact supports one of the arguments that usually lead to intervention: the monetary authorities tend to stabilise the market.

As for the US Fed interventions, the results are as follows: for the first and the second regime, a relationship between the movement of the exchange rate and interventions was statistically significant and with a right sign. There is also a statistically significant dependency between the intervention and market dispersion, with a positive sign. The possible reason for this is that the US monetary authorities have more confidence among market participants than the monetary authorities of Japan, and the corresponding actions on their part in most cases lead to a definite result. Unfortunately, about the foreign exchange market, the US Fed's actions have a negative effect: the positive sign of the coordination coefficient in the equation of variation means that the Fed "shakes the boat". Given this fact, the real failure of the US monetary authorities to intervene in the foreign exchange market (in 1998, the last US intervention in respect of the yen was observed) may seem entirely reasonable.

In our study, we have conflicting results about the effect of the foreign exchange interventions on the volatility of the dollar/yen exchange rate.

1. 02.01.1991 – 31.05.1995: infrequent interventions of the small scale – positive effect on the volatility;
2. 01.06.1995 – 31.12.2002: frequent interventions of the small scale – negative effect on the volatility;
3. 01.01.2003 – 31.03.2004: frequent interventions of the great scale – no effect on the volatility;
4. 01.04.2004 – 30.12.2011: a single sequence of interventions in 2011 – no effect on the volatility.

As it has been stated above studies which were conducted on the same data sample as we use and also employing GARCH-like specifications demonstrate mixed results on the influence of the foreign exchange interventions on the volatility. Thus, Nagayasu (2004), Kim and Sheen (2006), who examine the effect on the volatility caused by interventions by the joint estimation of conditional variance and conditional mean, have found a positive relationship between these two variables on the full data sample from 1991 till 2004.

But in our study, we are more interested not in estimating the effect on the entire data sample but rather in the different sample periods or types of intervention policy. In their studies, Beine (2004), Hillebrand and Schnable (2006), Kim (2007), Kim and Le (2010), Hassan (2012) support our main findings of the first intervention regime that there is the positive (increasing) effect on the volatility caused by interventions. There are also other factors which the one should take into account:

1. Interventions should be public and coordinated. And as we can see from our output operations coordinated with the US Fed during the first regime also have a significant effect on the volatility of the dollar/yen exchange rate. In their study, Kim and Le (2010) demonstrate with the GARCH-like specification that secret interventions have a negative (decreasing) effect on the volatility, while public interventions, especially during Tokyo trading, still have a tendency to increase the conditional variance of the dollar/yen exchange rate. Hassan (2012) have found some evidence of negative intervention effect on the volatility during the first regime, but it is true only for unilateral sales of yen without coordination with Fed.
2. Interventions should be conducted during Tokyo trading.

As the main finding for the first intervention regime which lasted from 1991 until May 1995 and is characterized with infrequent interventions of the small scale, we can conclude that depreciating operations of selling yen and buying US dollars which were coordinated with US Fed have positive, means increasing effect on the volatility of the dollar/yen exchange rate.

Watanabe and Harada (2006) who also used GARCH-like specification in their paper estimated a system of three, not two, equations to account for their hypothesis that volatility consists of both short-term and long-term components. According to their results for the first regime, there is no impact of interventions on the long-term volatility while the effect is negative for the short-term conditional variance for not coordinated interventions. Hassan (2012) supports the absence of any relationship between the interventions and the volatility only for not coordinated appreciating interventions.

According to the results of the second regime which lasted from June 1995 until the end of the year 2002 and is characterised with infrequent interventions of the great size depreciating operations have negative, means decreasing, effect on the volatility of the dollar/yen exchange rate, although the coefficient value is tiny. Watanabe and Harada (2006) demonstrate for the second regime the BoJ's intervention reduces the

volatility of the yen/dollar exchange rate, but the US Fed's coordinated intervention does not enhance this stabilising effect. The last statement is also true for our results as estimated coefficient for dummy variable which reflects the coordination of the interventions with US Fed is significant and has a positive value which means coordinated interventions under the second regime tended to increase the volatility of the dollar/yen exchange rate.

In most of the studies, the start of the second regime is associated with the appointment of Eisuke Sakakibara as Director General of the MoF's International Finance Bureau in June 1995. But Hillebrand and Schnable found a structural break around the turn of the millennium. As a result, they divide the data into two regimes: from 1991 up to the late 1990s when Japanese foreign exchange interventions seem to have an increasing effect on the exchange rate volatility. Starting from the late 1990s, it seems to have the reducing effect on the volatility. From our perspective, despite the time shift, we can say that their findings also support our results for the second intervention regime.

For the third regime, we have not found any statistically significant relationship between the frequent depreciating interventions of the great scale and the volatility of the dollar/yen exchange rate. We investigate this regime separately from the second one which might have caused certain problems due to the shortness of the data subsample (only 326 observations) and quite week specification of the ARIMA model as we had to regress the daily logarithmic returns on the error term, assuming that exchange rate is following a random walk.

In some studies, such as Kim and Sheen (2006), Kim (2007) and Kim and Le (2010), the second and the third intervention regimes are considered together. For example, Kim (2007) argues that for daily exchange rate data interventions increase the currency market volatility both under the first regime and the second and the third intervention regimes combined. In contrast to this for the intra-daily data, this kind of effect of interventions on the volatility has a tendency to decrease when trading moved from Tokyo to New York (in this study data consist of Tokyo, London and New York trading). What is more, during London and New York trading the impact of intervention became significantly negative.

For the first and the second intervention regimes, it is also important to note that in some situations monetary authority which is responsible for the intervention policy has to choose between two goals – whether they want to affect the level of the exchange rate or whether they aim to minimise the volatility of the currency market.

As we can observe from the Appendix D under the first regime depreciating interventions can be recognised as the successful ones in reducing the exchange rate daily returns (although with very tiny estimated value of -0,000004) but at the same time, these interventions resulted in the increased conditional variance. Hassan (2012) supports our finding with the conclusion that successful depreciation was achieved at the expense of higher volatility. In this study author also accounts the separate effects of frequency and size. Thus, more frequent intervention operations have a negative effect on both efficiencies regarding the level of the exchange rate and the volatility. Our results support the finding regarding the conditional mean as we can see that under the first regime interventions successfully reduced the level of the dollar/yen exchange rate while the volatility increased. On the other hand, we can conclude that it is true if we discuss opposite goals of the interventions under the first and second regimes. During 1991-1995 the BoJ was aiming to affect the level of the exchange rate so the increased volatility can be considered as the aside negative effect of the successful intervention policy as the level of the dollar/yen exchange rate declined. Contrary to this, during 1995-2002 the BoJ was to trying to stabilise the market and break a trend of appreciating yen. In this case, infrequent interventions of the greater scale successfully reduced the conditional variance of the exchange rate although the conditional mean has not been affected by the intervention operations conducted. Hoshikawa (2008) analyses the entire data sample and shows that frequent interventions are less effective regarding the effect on the level of the exchange rate, but they are willing to reduce the volatility of the currency market. As a result, his findings contradict with ours, but we suppose that it is not always efficient to apply the results of the examination of the full sample (which are recognised in most of the studies as inconclusive) to the two different intervention regimes.

Under the fourth regime, intervention operations do not follow any specific pattern, so this data subsample cannot be called “regime” in a way that we apply this term to three latter periods. As we can observe from the Appendix D from April 2004 till the end of 2011 both the level and the volatility of the dollar/yen exchange rate have not been affected by the foreign exchange interventions.

The first intervention was conducted in September 2010. Its goal can be defined as the demolition of the yen’s upward trend against the US dollar, which arose after the crisis of 2008. The significant strengthening of the yen to major world currencies led to a sharp drop in revenues from export operations. Official authorities began to take active measures when the dollar’s exchange rate against the yen reached a 15-year low, falling below 83. The intervention was conducted on September 15, 2010, during which the BoJ spent 2 124,9 billion yen. Since it was necessary to increase the yen’s

offer in the market, the central bank sold the national currency and bought US dollars. During trading on September 15, 2010, the yen's exchange rate changed from 82,83 to 85,77 per US dollar. As a result of trading, the depreciation of the Japanese currency was 3.5%. The target of intervention is 85 yen per dollar. At this point, the yen lasted seven days; then the currency began to grow again. A month after the intervention, the exchange rate was 81,41 (-5% of the intervention level), after six months – 80,70 (-5,9%). Thus, we can conclude that in the ultrashort period a positive effect was achieved by the intervention, but in the remaining periods, the results were negative (neither short-term nor medium-term upward trends were broken).

The second intervention was carried out by the MoF on 18.03.2011. Its conduct was caused by a sharp increase in the yen's rate to major world currencies in connection with the earthquake on 11.03.2011. For a few days after the disaster, the yen to dollar rate increased by 6,6% (from 81,88 to 76,43). During this period, the BoJ actively conducted consultations with central banks of G7 countries, during which agreements on collective intervention were reached, which was held on 18.03.2011, the volume of transactions amounted to 692,5 billion yen.

We will evaluate the results of this operation, the purpose of which can be defined as the retention of the exchange rate near the target benchmark - 80 yen per US dollar and above. In the course of trading on 18.03.2011, the yen fell by 3,9% - from 78,90 to 81,99, at this level, it lasted seven days. A month later, the yen to the US currency was 83,26 (2.4% to the level of intervention), after four months. – 79,06 (-3,5%). Above the mark of 81 yen per dollar rate was 64 days. It can be stated that this currency intervention was effective in the short and short-term periods, the remaining time intervals - the result is negative.

The third intervention was conducted on 04.08.2011. The target was also a rate of 80 yen per dollar. During the trading session, the rate has overcome this mark, but could not gain a foothold there and stopped at the level of 79,06. Already on the next day (05.08.2011), the trades ended at around 78,47, and in the future, the yen continued to strengthen against the dollar. The duration of the BoJ's operations was one day, the total amount – 4 512,9 billion yen.

In October-November 2011 there was the last series of interventions from 31.10.2011 till 04.11.2011, the total amount was 9 091,7 billion yen. After the first intervention of the greatest size (8 072,2 billion yen) the exchange rate increased from 75,82 yen per US dollar to 78,32. Until the end of the intervention series, the level of the exchange rate was fluctuating around the mean of 78,19 yen per US dollar with the

average intervention amount of 254,88 billion yen. The level was in the corridor between 76 and 78 until the beginning of February 2012, then it started appreciating and achieved its maximum (83,83 yen per US dollar) on March 14, 2012. All foreign exchange interventions conducted by the Japanese monetary authorities after the year 2004, unfortunately, turned out to be ineffective regarding the effect on the level of the dollar/yen exchange rate and volatility.

One of the potential reasons the interventions of the Japanese government ended unsuccessfully is the high demand for the Japanese national currency by non-residents. This demand is formed by portfolio investors and speculators. Investors view Japanese government debt securities as a "protective asset" along with precious metals. As soon as the dollar and euro begin to depreciate, investors sharply increase the demand for "protective" assets, thereby contributing to the appreciation of the yen.

Speculators are actively using the carry-trade strategy for Japanese financial assets. The essence of this strategy is that in a country with a low-interest rate they borrow money, buy assets with them in foreign currency, which will rise in price, after a certain time, the asset is sold, the foreign currency is changed into national currency, they receive income and return a loan. The income of speculators consists of two components: income from a foreign asset in the form of interest rate and exchange rate difference. It is the second component that is most significant and brings large profits to the speculators. After the crisis of 2008, the US Fed lowered the interest rate to 0,25%. Also, government bonds were redeemed to increase the amount of money in the financial system. Banks and investment companies formed excess liquidity, which had to be invested in some short-term assets, while the quantitative easing of the US Fed. For example, buying a Japanese yen in 2009, it was possible to earn on changes in rates up to 6% in annual terms, and in 2010 - up to 12% per annum. This is a very high yield compared to traditional savings instruments: bank deposits and government bonds. Of course, the high return on investment in a foreign asset is always associated with a high risk. But the peculiarity of currency transactions with the Japanese yen is that players in the market are firmly confident in maintaining the growing trend for a long time, also, by their active purchases, traders strengthen the growing trend.

Thus, all the reasons considered in its entirety do not allow the MoF, with the help of currency interventions, to reverse the situation in the foreign exchange market. At present, Japan feels the urgent need to stop the flow of short-term speculative capital to its financial market. The practice has shown that neither monetary measures nor

currency interventions are currently effective. Therefore, it is necessary to introduce tax instruments actively.

5. Conclusion

In this thesis, we use GARCH-in-mean model to evaluate the effects of the foreign exchange interventions conducted by the BoJ in the timeframe of 1991-2011 on both level and volatility of the dollar/yen exchange rate. We add external independent variables to extend the model and use all the intervention data which are available for the analysis at the moment. The full data sample was divided into four subsamples with the dividing points commonly accepted in the related literature.

According to the results that we have obtained from the separate estimation of the model under each of the intervention regimes, we come a conclusion that appreciating interventions do not have any significant effect neither on the level nor the volatility of the dollar/yen exchange rate. At the same time, depreciating interventions can trigger daily logarithmic returns when interventions are small and frequent but not when they are infrequent and large. We have found that depreciating interventions may have opposite effect on the volatility depending on their frequency and size. Thus, under the first regime volatility was increased by the operations of the Japanese monetary authorities but it was decreased under the second regime. Considering the first and the second subsamples which lasted from the year 1991 until March 2004 Japanese interventions were coordinated with the US Fed and these concerted actions have increased the volatility.

Trying to control for the market conditions in the both Japanese and the US economies we include daily logarithmic returns of the most important market indices. According to our results volatility of the foreign exchange market in Japan is not affected by the alteration of the Nikkei index while it is partly determined by the movements of the Dow Jones Industrial Average. It again demonstrates us consistent dependency between the Japanese and American markets, especially when export and import balance is involved as it is the case for the exchange rate.

Our motivation to use the GARCH-in-mean model was to examine if there is a dependency between the level of the exchange rate and its current volatility and to find if risk affects the returns under the particular intervention techniques employed by the BoJ. As *archm* component is significant only under the first regime, we cannot say that there is strong dependency between the conditional mean and conditional variance of the dollar/yen exchange rate.

We cannot see any considerable effect of the “news” or “surprises” on the conditional variance except for the fourth regime, so it does not seem the shocks, including the interventions, used to have any destabilising effect on the volatility of the market. On the other hand, the forecast variance from the previous periods does alter the current conditional variance under the second, third and fourth intervention regimes which support the major role of the persistence in volatility in the determination of the current level of the conditional variance for these three subsamples.

Most of the studies conducted in previous years do not support our finding of the volatility under the third intervention regime. They either support the positive effect of the interventions on the volatility such as Hassan (2012), or the negative one as Hillebrand and Schnabl (2006). As in our study, we consider all the data subsamples separately we have not combined the second and the third regime although the other researchers had widely employed this approach. Under the third regime when interventions were frequent and of the great scale according to our results only the Dow Jones Industrial Average, means aggregated market situation in the US has a significant effect on the volatility.

As for the remaining subsample that we call the “fourth” regime none of our external independent variables result in significantly estimated coefficients, so we try to analyse every operation separately regarding their effect mostly on the level of the exchange rate. We come to a conclusion that these interventions cannot be recognised as the successful ones as they could not force the exchange rate to stick to the target mark, although it was possible to achieve the goal within one trading day. This finding is also supporting regarding the short-lived impact of the intervention operations.

There are some factors which affect the volatility and level of the exchange rate in the market and single intervention cannot be claimed as a universal tool which can change the long-term trend of the exchange rate development. On the other hand, as it can be observed from our findings, if interventions are conducted on as a consistent, planned and systematic series operations they can achieve their main goal, whether it is a certain level or the reduction of the volatility. In the ideal case, there should not be a trade-off for the monetary authority, but in reality, the BoJ has to sacrifice either the desired level of the dollar/yen exchange rate which is the of the extremely important indicators determining the trading balance of Japan, or stability of the currency market.

The research on the volatility and its vulnerability under the interventions can be continued by fitting GARCH-in-mean model on the combined intervention regimes.

Also, the main point is that modelling the consequences of foreign exchange interventions for the exchange rate one cannot do without key macroeconomic indicators, such as national income, money supply, trading balance parameters. On the other hand, data on foreign exchange interventions are provided daily, while key macroeconomic parameters are at best monthly or quarterly. Thus, it would be problematic to include such heterogeneous data in the model. The problem of aggregating data - translating information on interventions into an annual or quarterly form or disaggregating - translating macroeconomic statistics into a form, at least, weekly, may prove to be unsolvable. Perhaps this is one of the problems why most of the empirical studies on the investigation of the foreign exchange interventions do not rely on macroeconomic statistics. It can be an innovative way to assess the real intervention effect more deeply if it would be possible to account for the market conditions not only by using aggregated indices but also by the inclusion of the real economic indicators.

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Appendix A: Description of the former empirical studies

Authors	Dominguez	Beine Laurent Lecourt	Ito	Fatum Hutchison	Nagayasu
Title	Central bank intervention and exchange rate volatility	Official Central Bank Interventions and Exchange Rate Volatility: Evidence from a Regime Switching Analysis	Is Foreign Exchange Intervention Effective?: The Japanese Experience in the 1990s	Effectiveness of Official Daily Foreign Exchange Market Intervention Operations in Japan	The effectiveness of Japanese foreign exchange interventions during 1991-2001
Year	1998	2001	2002	2003	2004
Exchange rates to analyse	DEM/USD YEN/USD	DEM/USD YEN/USD	Yen/dollar	Yen/dollar	Yen/dollar
Time horizon	1977-1994	1985-1995	1991-2001	1991-2000	1991-2001
Object of analysis	Volatility	Level Volatility	Effectiveness of the interventions	Effectiveness of intervention	Effectiveness of interventions
Approach	GARCH	Regime dependent approach	Regression analysis Reaction function	Event study methdology (non-parametric sign test/ matched sample test)	GARCH model

Outcomes	1. Changes in monetary policy and intervention policy often influence exchange rate volatility but it is not volitility that causes intervention. 2. Intervention need to be publicly known in order to influence volatility. 3. Secret interventions generally increase volatility. 4. Reported central bank intervention: full sample - lead to an increase in daily and long-term exchange rate volatility/ mid-1980s - led to reductions on volatility.	1. The positive effect of central bank interventions on exchanged rate volatility partly confirmed. 2. When market is highly volatile and market participants expect the central bank to intervene, concerted interventions can have a stabilizing effect (signalling approach). 3. Coordinated interventions lead to large effects in the foreign exchange market rather than unilateral ones. 4. Impact of the intervention in the exchange rates depends on the current state of the market and the perceived motivation to intervene (more	1. Intervention strategy employed by Sakakibara seemed to be distinctively different from his predecessors. 2. The Japanese interventions during the 1990s produced large profits from realized capital gains, unrealized capital gains and profits from the interest rate differentials. The Japanese monetary authorities were judged as a successful, thus stabilizing, speculator, earning close to 9 trillion yen in ten years. 3. A regression analysis reveals that intervention during the second half of the 1990s in Japan produced intended	1. Sterilized intervention systemically affects the exchange rate in the short-run. 2. Large-scale intervention operations characterized by the simultaneous presence in the foreign exchange market by both the Bank of Japan and the Federal Reserve gave by far the highest likelihood of success. 3. Intervention found to be effective even if not accompanied by supporting interest rate changes. 4. Short-run effectiveness of intervention found support. 5. Consistent with recent literature interpreting	1. The importance of including intervention variables when modeling exchange rate volatility is underscored. 2. Relatively stronger evidence in favor of the use of concerted interventions is provided. 3. An increase in uncertainty due to intervention operations. 4. Findings reported are generally consistent with previous research using perceived interventions data.

		transparent intervention policy).	effects on the yen. The US intervention in the yen/dollar market was more powerful than the Japanese unilateral intervention.	intervention as a means to "signal" not only future policy but also the central bank's views on the fundamental/equilibrium value of the exchange rate.	
Authors	Chaboud Humpage	Beine Szafarz	Watanabe Harada	Hillebrand Schnabl	Beine
Title	An Assessment of the Impact of Japanese Foreign Exchange Intervention: 1991-2004	Size matters:Central bank interventions on the Yen/Dollar exchange rate	Effects of the Bank of Japan's Interventions on Yen/Dollar Exchange Rate Voltility	A Structural Break in the Effects of Japanese Foreign Exchange Intervention on Yen/Dollar Exchange Rate Volatility	Why Do Central Banks Intervene Secretely? Preliminary Evidence from the BoJ
Year	2005	2006	2006	2006	2007
Exchange rates to analyse	Dollar-yen	YEN-USD	Yen/dollar	Yen/dollar	YEN/USD
Time horizon	1991-2004	1991-2001	1991-2003	1991-2004	1991-2004
Object of analysis	Short-term effectiveness of intervention	Impact/effectiveness of central bank interventions	Volatility Level	Effects of intervention on volatility	Reason of the use of secret central banks' interventions

Approach	Criteria/ probit regressions	GARCH (1,1)	component GARCH model	GARCH	Binary response model
Outcomes	1. For the sample as a whole, Japanese intervention operations had little predictive power as to the daily direction of exchange rate movements. 2. Japanese intervention operations between 1991 and 2004 were associated with a substantially higher-than-expected frequency of both moderation and reversals in daily exchange rate movements, and therefore had forecast value relative to these two types of events. 3. Intervention operations conducted in coordination with	1. Unilateral operations are in general either ineffective or even counterproductive. 2. Isolated large-scale interventions can produce the desired effects in terms of the exchange rate level. 3. Large-scale operations should be favoured by the Bank of Japan.	1. The BOJ's intervention reduced only the short-run volatility component in the second half of the sample period, while it did not have any impact on volatility at all in the first half of the sample period. 2. The stabilizing effect of the BOJ's intervention in the second period was not enhanced by the Fed's coordinated intervention.	1. Global GARCH estimations are inconclusive. 2. Local estimations confirm a structural break ocurring around the term of the millenium when Japanese foreign exchange intervention could effectively remain unsterilized as a result of liquidity trap. 3. Up to the late 1990s, Japanese foreign exchange intervention correlates with increased volatility of the yen/dollar exchange rate. 4. After 1997 foreign exchange intervention is associated with lower exchange rate	1. The size of the amounts used in the interventions, coordination with another central bank as well as the presence of recent past operations are found to improve the detection of central bank operations. 2. The Bank of Japan tended to favor secret operations when it was targeting its own level and when acting in the opposite direction to reducing the exchange rate misalignment. 3. No evidence in favor of a noise trading strategy of the BoJ in the sense that its actions would have targeted both

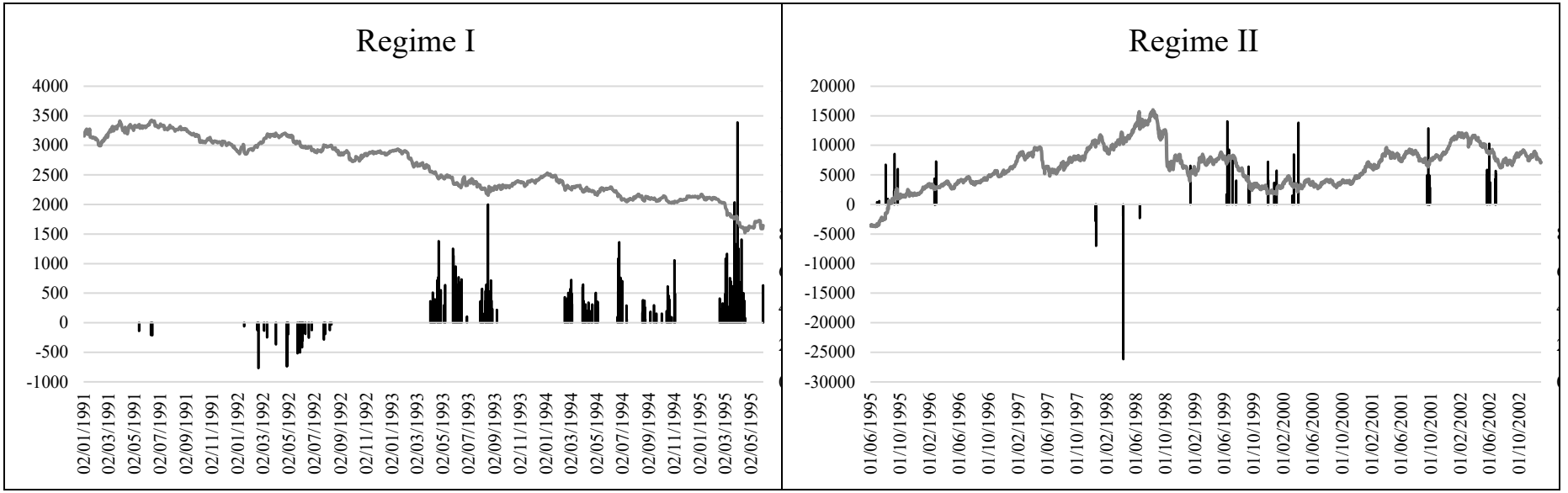
	those of U.S. monetary authorities, which occurred mainly in the early part of our sample period, met with a slightly higher frequency of success under several of our criteria than those of the Japanese authorities alone. 4. Japanese foreign exchange interventions had a modest, but clearly detectable, impact, on short-term movements in the dollar-yen exchange rate. 5. The large and rather infrequent operations conducted between mid-1995 and the end of 2002 met with a higher degree of success under several of our criteria.			volatility, thereby indicating exchange rate stabilization. 5. No support for a structural break in 1995 (shift from small intervention to large interventions) and there is no evidence that multilateral intervention may have mattered for this result.	fundamental and noise traders.

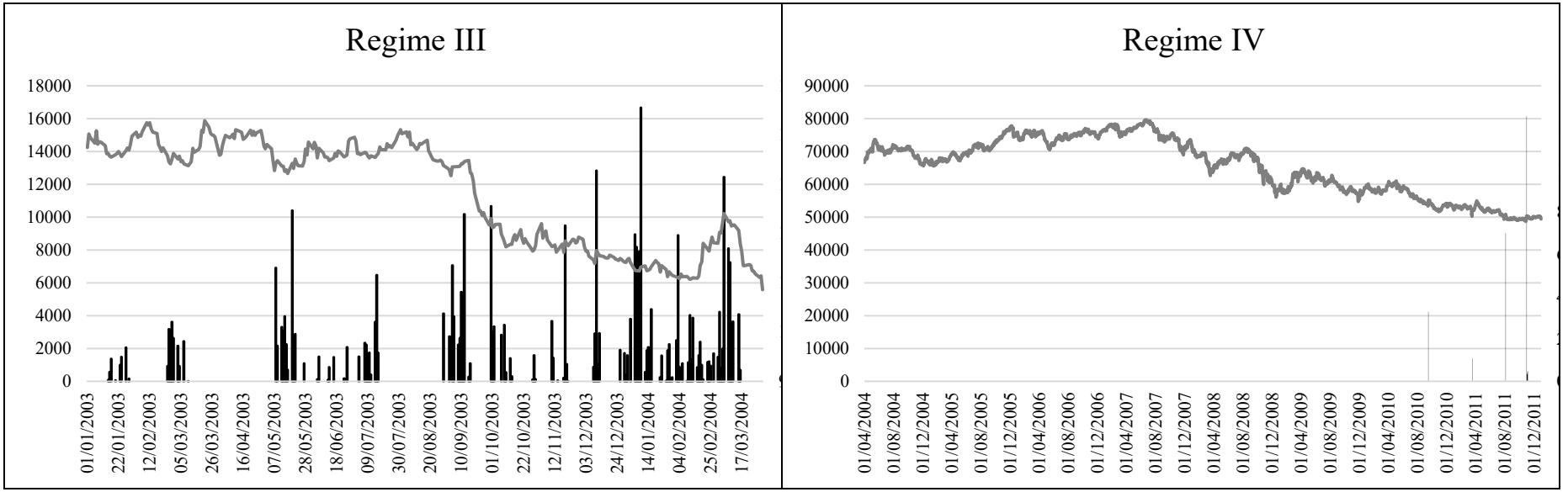
Authors	Suardi	Fatum	Dukich Kim Lin	Chortareas Jiang Nankervis	MacDonald Mao
Title	Central bank intervention, threshold effects and asymmetric volatility: Evidence from the Japanese yen-US dollar foreign exchange market	Official Japanese Intervention in the JPY/USD Exchange Rate Market: Is It Effective, and through Which Channel Does It Work?	Modeling Exchange Rates using the GARCH Model	Volatility and Spillover Effects of Yen Interventions	Japan's Currency Intervnetion Regimes: A Microstructural Analysis with Speculation and Sentiment
Year	2008	2009	2010	2011	2016
Exchange rates to analyse	Japanese yen-US dollar	JPY/USD	GBP/USD JPY/USD EUR/USD	daily/ intraday frequencies USD/JPY euro/JPY	JPY/USD
Time horizon	April 1, 1991 - March 31, 2003	1999-2004	1999-2010	2000-2004	1991-2004
Object of analysis	Regime changes	Effectiveness of intervention Distribution channel	Empirical adequacy	Effects of BoJ interventions on exchange rate volatility	Relations between currency intervention, speculation and sentiment and exchange rate movements
Approach	threshold GARCH model	GARCH	GARCH: (1,1)/ (1,2)/ (2,1)	Multivariate GARCH Quartile plots Equal variance test	Cointegrated VAR methodology

Outcomes	1. The effectiveness of foreign exchange intervention is dependent on the regimes of the exchange rates. 2. Interventions are more effective in periods when there is massive depreciation in the JPY against the USD. 3. Interventions by the two central banks are effective in reducing the volatility of returns to exchange rates only when the exchange rates are strongly appreciating.	1. Actual intervention , whether or not the market is aware of the intervention, exerts a significant same-day influence on the JPY/USD exchange rate. 2. The importance of the portfolio balance channel is supported by the data while no direct evidence of the information signaling channel is found. 3. Official statements made during the period under study do not contain enough new information to significantly affect the exchange rate market. 4. The first day of intervention following a no-intervention day has a larger than average impact on exchange rates. Some sample-specific	1. None of the GARCH models captured the empirical nature of LPR prices partucularly well (sudden shift after recent financial crisis). 2. Mixed results of residuals histograms.	1. The BoJ's interventions in the USD/JPY exchange rates decrease - although only in the short-term (less than 5 hours) and in a discontinuous pattern - the volatility of the USD/JPY series. 2. The interventions increase significantly the volatility of the euro/JPY series and the impact lasts for the whole of the intervention day. 3. Interventions have some impact (decrease) on the covariance of exchange rates. The evidence produced for the spillover effect and the impact on covariances can have direct implications for portfolio management purposes.	1. The fundamental factors and market conditions played important roles in the exchange rate dynamics. 2. In all three regimes, shocks to the bond yield differential had strong long-run impact on speculation and sentiment, and exchange rate movements. 3. The yield shocks stimulated speculation and sentiment on JPY, and worked as the main driving force of the whole system.

		evidence that the first day after intervention is associated with an adverse exchange rate adjustment is found. 5. Intervention on any given day, whether or not the market is aware of the intervention operation, contains an expected as well as an unexpected component.		4. The interventions affect volatility differently under different market conditions. 5. Interventions cause the intraday returns to become less heteroskedastic for both exchange rates.	

Appendix B.1: Absolute daily foreign exchange interventions and daily dollar/yen exchange rate returns

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18000
16000
14000
12000
10000
8000
6000
4000
2000
0
01/01/2003
22/01/2003
12/02/2003
05/03/2003
26/03/2003
16/04/2003
07/05/2003
28/05/2003
18/06/2003
09/07/2003
30/07/2003
20/08/2003
10/09/2003
01/10/2003
22/10/2003
12/11/2003
03/12/2003
24/12/2003
14/01/2004
04/02/2004
25/02/2004
17/03/2004
Regime IV
90000
80000
70000
60000
50000
40000
30000
20000
10000
0
01/04/2004
01/08/2004
01/12/2004
01/04/2005
01/08/2005
01/12/2005
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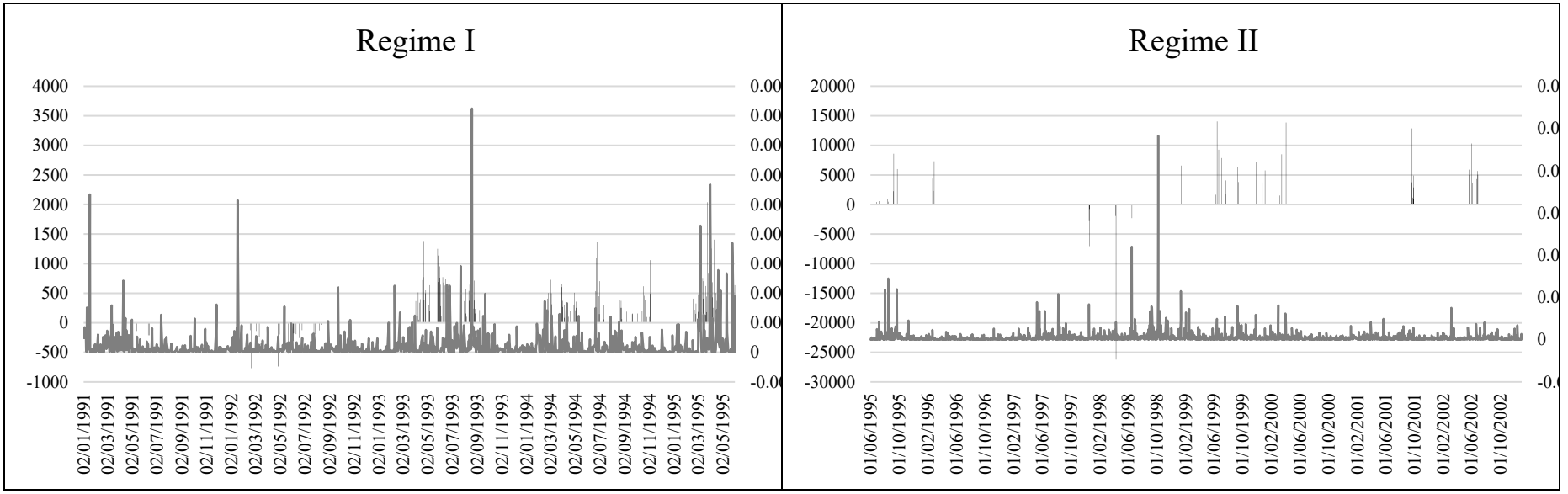
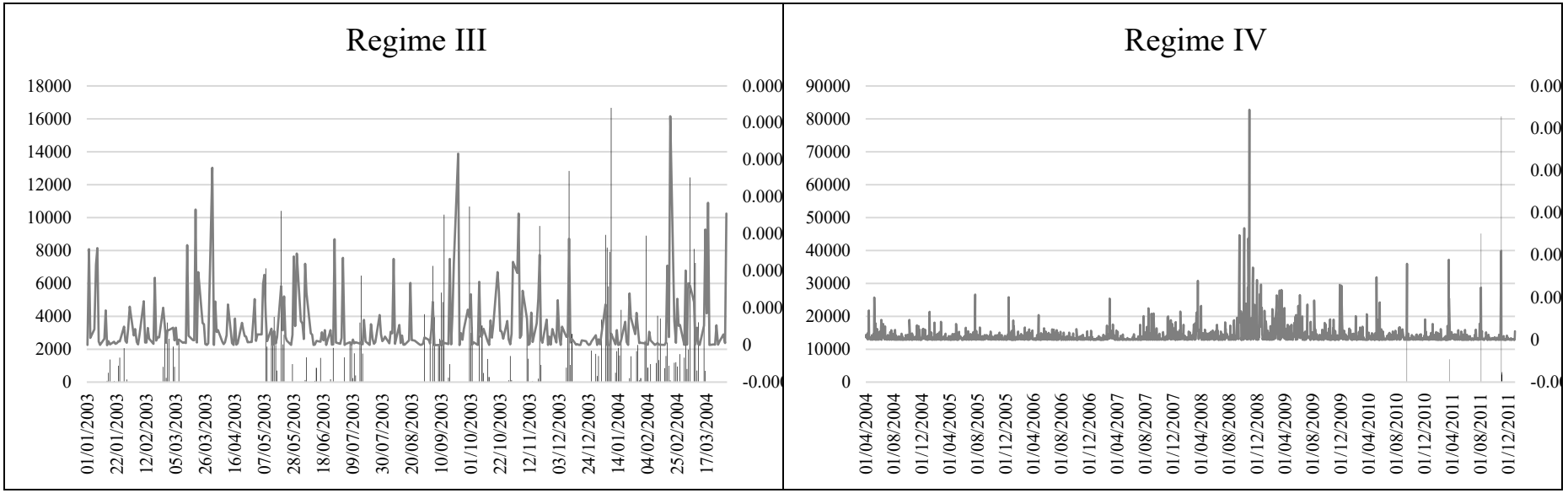
01/12/2011

Appendix B.2: Absolute daily foreign exchange interventions and daily dollar/yen exchange rate volatility




Regime III
18000
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01/01/2003
22/01/2003
12/02/2003
05/03/2003
26/03/2003
16/04/2003
07/05/2003
28/05/2003
18/06/2003
09/07/2003
30/07/2003
20/08/2003
10/09/2003
01/10/2003
22/10/2003
12/11/2003
03/12/2003
24/12/2003
14/01/2004
04/02/2004
25/02/2004
17/03/2004
Regime IV
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80000
70000
60000
50000
40000
30000
20000
10000
0
0.00
0.00
0.00
0.00
0.00
0.00
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-0.0
01/04/2004
01/08/2004
01/12/2004
01/04/2005
01/08/2005
01/12/2005
01/04/2006
01/08/2006
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01/04/2011
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01/12/2011

Appendix C: Comparison of BIC of various ARIMA models

ARIMA order	Regime I	Regime II	Regime III	Regime IV
ARIMA (2,0,2) with non-zero mean	-8 212,63	-13 670,86	-2 491,02	-14 279,99
ARIMA (0,0,0) with non-zero mean	-8 222,09	-13 701,87	-2 503,70	-14 286,76
ARIMA (1,0,0) with non-zero mean	-8 216,30	-13 693,61	-2 498,22	-14 293,02
ARIMA (0,0,1) with non-zero mean	-8 215,34	-13 694,55	-2 499,05	-14 294,76
ARIMA (0,0,0) with zero mean	**-8 224,88**	**-13 708,41**	**-2 507,50**	-14 293,44
ARIMA (1,0,1) with non-zero mean	-8 211,20	-13 686,02	-2 492,84	-14 288,10
ARIMA (0,0,2) with non-zero mean	-	-	-	-14 290,23
ARIMA (1,0,2) with non-zero mean	-	-	-	-14 287,79
ARIMA (0,0,1) with zero mean	-	-	-	**-14 301,25**
ARIMA (1,0,1) with zero mean	-	-	-	-14 294,52
ARIMA (0,0,2) with zero mean	-	-	-	-14 296,63

ARIMA (1,0,2) with zero mean	-	-	-	-14 294,26
Minimum value of criteria	-8 224,88	-13 708,41	-2 507,50	-14 301,25

Appendix D: Model output

Regime I					
	Estimate	Std. Error	t value	Pr(>|t|)	
μ	0,00	0,00	-6,61	0%	***
β_1	0,05	0,01	7,96	0%	***
b	0,000003	0,00	0,98	33%	-
s	-0,000004	0,00	-5,03	0%	***
c	0,002	0,00	13,31	0%	***
n	-0,04	0,01	-3,55	0%	***
d	0,05	0,00	13,44	0%	***
α	-0,05	0,06	-0,92	36%	-
β	-0,05	0,10	-0,52	60%	-
γ	0,22	0,08	2,85	0%	***
b	-0,001	0,00	-1,16	25%	-
s	0,001	0,00	3,55	0%	***
c	1,52	0,44	3,47	0%	***
n	3,69	3,87	0,95	34%	-
d	7,60	7,03	1,08	28%	-

Regime II					
	Estimate	Std. Error	t value	Pr(>|t|)	
μ	0,00	0,00	0,27	79%	-
β_1	0,01	0,04	0,22	83%	-
b	0,000001	0,00	1,95	5%	-
s	0,000001	0,00	1,20	23%	-
c	0,02	0,00	32,61	0%	***
n	-0,02	0,01	-4,02	0%	***
d	0,06	0,02	3,69	0%	***
α	-0,02	0,02	-1,59	11%	-
β	0,98	0,00	7 177,47	0%	***
γ	0,09	0,00	28,75	0%	***
b	-0,00001	0,00	-0,62	54%	-
s	-0,00003	0,00	-2,07	4%	***
c	0,82	0,31	2,67	1%	***
n	0,50	1,07	0,46	64%	-
d	-3,28	1,25	-2,62	1%	***

Regime III					
	Estimate	Std. Error	t value	Pr(>|t|)	
μ	0,00	0,00	0,30	76%	-
β_1	-0,27	0,39	-0,69	49%	-
s	0,00	0,00	0,17	86%	-
n	-0,05	0,03	-1,85	6%	-
d	0,06	0,04	1,45	15%	-
α	0,13	0,09	1,36	17%	-
β	0,62	0,15	4,26	0%	***
γ	0,24	0,28	0,83	40%	-
s	0,00	0,00	-0,13	89%	-
n	-10,49	5,64	-1,86	6%	-
d	20,45	6,70	3,05	0%	***

Regime IV					
	Estimate	Std. Error	t value	Pr(>|t|)	
μ	0,00	0,00	-0,99	32%	-
ma1	-0,05	0,03	-1,92	5%	-
β_1	0,04	0,07	0,54	59%	-
s	0,00	0,00	18,94	0%	***
n	0,03	0,02	1,83	7%	-
d	0,15	0,05	2,89	0%	***
α	-0,05	0,02	-2,74	1%	***
β	0,97	0,01	172,03	0%	***
γ	0,14	0,03	4,73	0%	***
s	0,00	0,00	-1,19	23%	-
n	-1,88	1,23	-1,53	13%	-
d	-3,67	1,99	-1,85	6%	-